DOE/NASA CONTRACTOR REPORT

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PROTOTYPE SOLAR HEATING AND COMBINED HEATING AND COOLING SYSTEMS (QUARTERLY REPORT NO. 3)

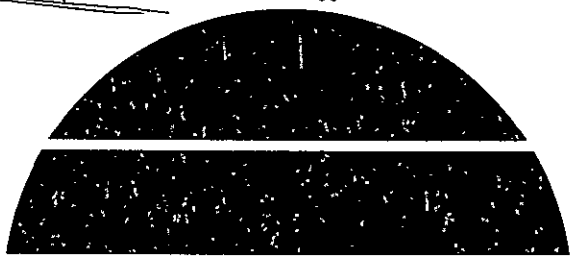
Prepared by

General Electric Company
Space Division
Post Office Box 8661
Philadelphia, Pennsylvania 19101

Under Contract NAS8-32092 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy



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This work was accomplished under the technical management of Mr. William L. Moore, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

The General Electric Company is developing eight prototype solar heating and combined heating and cooling systems. This effort includes development, manufacture, test, installation, maintenance, problem resolution, and performance evaluation.

~~All cost data have been~~ removed from this report.

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QUARTERLY REPORT NO. 3
MONTHLY REPORT NO. 9

SOLAR HEATING AND COOLING SYSTEM DESIGN AND DEVELOPMENT

CONTRACT NAS 8-32092

DATA REQUIREMENT NO. 500-10
DATA REQUIREMENT NO. 500-11

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INTRODUCTION

The Quarterly Status Report (Data Requirements Item No. 500-10) provides a summary of the cost, schedule and technical progress of the program. Since it includes and extends the information included in the Monthly Status Reports (Data Requirements Item No. 500-11) it also meets the contract requirement of a monthly status report. It is supplemented by the financial status report (Data Requirements Item No. 500-27) submitted under separate cover.

The report format is:

Part I - Summary

Part II - Cost

Part III - Schedules

Part IV - Technical Performance

The report is integrated with the program management systems being used on the program, so, where possible, multiple use of program data such as schedules or financial status reports has been accomplished.

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PART I

SUMMARY

PART I

SUMMARY

1.1 COST

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1.2 SCHEDULE

The working program schedule is posted on the walls of the Program Control Room and is used to monitor program status at daily "standup" meetings. Reviews with GE management are held in the Control Room to take advantage of the detail schedule data base. A summary schedule is shown in Figure 1-1.

Definition of the Operational Test Sites was a continuing schedule problem. The initial prototype design review was rescheduled and rescoped to adapt to the number and dates of the identified sites.

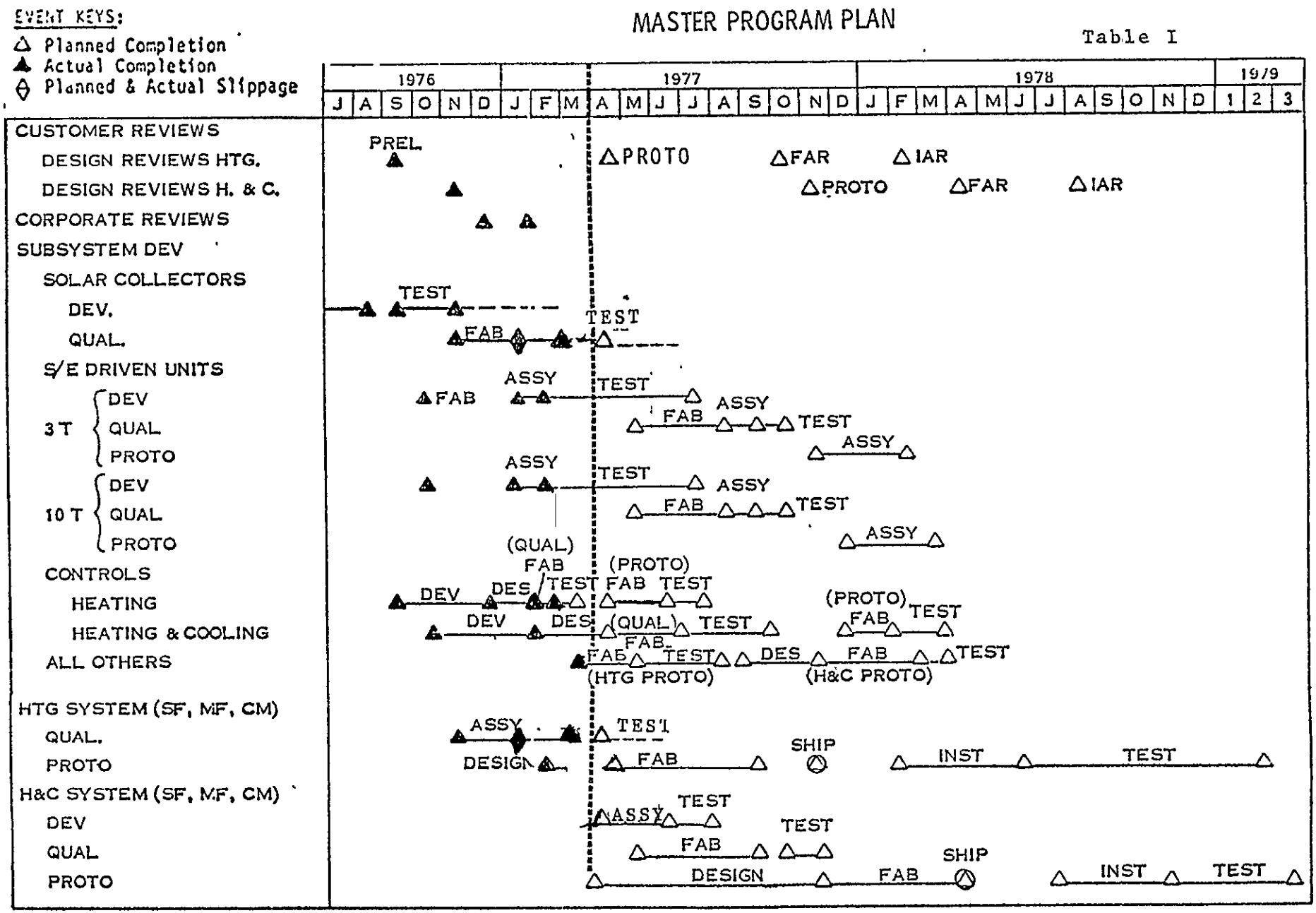

Figure 1-1. Master Program Plan

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MASTER PROGRAM PLAN

Table I Cont'd.

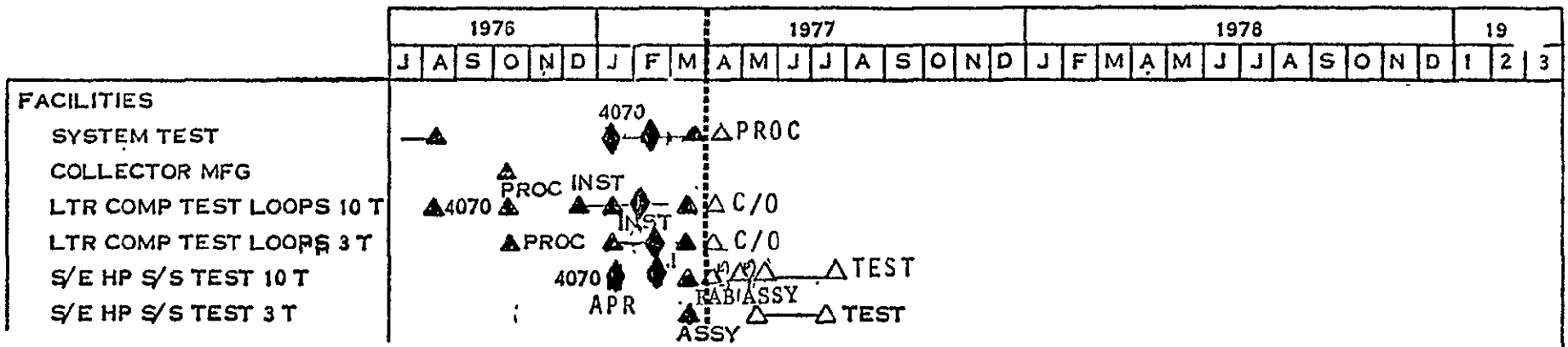

Figure 1-1. Master Program Plan (Cont)

Hardware testing became an important schedule factor this period. Testing of the qualification collector and low temperature Rankine engine components did not progress at the planned rate of progress this period. Planning adjustments are being made.

1.3 TECHNICAL PERFORMANCE

Program technical status is reflected by key events during this period: Completion of a comprehensive series of performance tests on solar collectors; completion and initial tests of 3 ton and 10 ton expanders; completion of controls components (solar integrator and analog sensor logic unit); completion of the major portion of "all others" specifications needed for heating system; and completion of heating system test loop.

Highlights of the technical accomplishments and the data summarized in Section IV of this report are as follows:

WBS 1.1.1	Program Direction	Quarterly program review. GE Corporate Review Team Meeting
WBS 1.1.2	Program Control	Schedule Monitoring
WBS 1.1.3	Quality Assurance	Meetings with AFPRO on approach. Potential problem of scope of delegation authority identified. NASA informed.
WBS 1.2.1	Analyses and Integration	Performance goals for Cycle 2 cooling subsystems. System trades. Analytically verified simplified control scheme.
WBS 1.2.1.1.1 1.2.2.2.2	Solar Collector Development	Qualification units completed, but problem surfaced after shroud installation. Collector loop engineering tests setup and tests initiated.
	"All Others"	Specifications issued.
WBS 1.2.3.1.7 1.2.3.2.7	Controls	Fabrication of solar integrator and logic units. Simplified design concept initiated and design complete.

WBS 1.2.3.1.1	Solar/Electric Driven Heat Pump (Air Conditioner)	Completion of major Cycle 1 hardware items. Expander performance verified on test stands (3 and 10 ton). Testing problems being resolved. Control work initiated.
WBS 1.2.3	Test	Two LTR test loops completed and two more under construction. Subsystem and system test stands approved and construction started. Resolving problems with test loops (A). Heating system test set up and tests started.
WBS 1.3	Deliverable Hardware	Long lead item procurement for heating only. Residential solar collectors initiated.

A key event during this period was the acceptance of the recommendation to develop the 3 and 10 ton solar cooling subsystems. There have been numerous discussions of this topic with the key consideration in deleting the 20 ton unit being its limited market potentials.

1.4 VARIANCES

Requested variance data is summarized in Table 1-2

Table 1.2. Program Variances

TYPE OF VARIANCE COST	SCHED	PERF	REASON FOR VARIANCE	IMPACTION TASK	IMPACT ON CONTRACT	CORRECTIVE ACTION
	X		Testing costs are not tracking plan	1.2.3	None	Testing being scheduled to meet program need: Time phasing being revised
X	X		Delays in operational test site identification	1.2.2 1, 1.3.1, 1.4.1, 1.1	Can impact cost and schedule	Plans have been continuously updated to adju to site selections
X	X		Problems with shrouds upon installation on qualification units on test stand. Qual. testing delayed	1.2.2 1.1 & 1.2.2.2.1	Being assessed.	Failure analysis plus design modifications. Problem did not occur with engineering model designs.
X	X		Variance in delays in completion of performance tests on LTR components. Early delays were due to stretch out in test unit fabrication cycles. Problems were encountered with checkout of test loops and delays occurred in the completion of the 3 loops. Some expander vane breakage has required minor hardware rework and has delayed testing of units (particularly 3 Ton).	1.2.3 & 1.2.2	Being analyzed. Data base needed to design next cycle of cooling hardware.	Focusing efforts of team on problems. Obtaining technical assistance from GE - Evandale.

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PART II

COST

This section has been deleted

PART III

SCHEDULES

PART III

SCHEDULES

Summary program schedules are shown in Figures 3-1, 3-2, and 3-3. These schedule data are extracted from the detailed program working schedules posted in the Control Room at Valley Forge.

Figure 3-1 is a summary key events schedule. Unlike the previous periods there were no major customer events during the period. The Prototype Design Review originally scheduled during the period had to be postponed due to delays in operational test site identification.

Principal events included fabrication of qualification solar collectors. As reported elsewhere problems were encountered upon installation of the shrouds and are being worked. Three (3) and 10 ton expanders were completed and put on test during this period. Performance mapping and materials investigations were not completed this period due to both hardware and test loop problems. The second set of loops to test other engine components was not completed this period and planned component testing was not completed. This has delayed the data base for the design of the next cycle engine.

In the controls area the solar integrator unit for qualification was assembled but testing was not started. The logic section of the controls package was simplified significantly when system analyses shows that analog temperature sensors could be eliminated. The revised unit, a simple relay circuit, was designed during this period.

Specifications for use in ordering "all others" for the heating prototype systems were completed and vendor contact initiated.

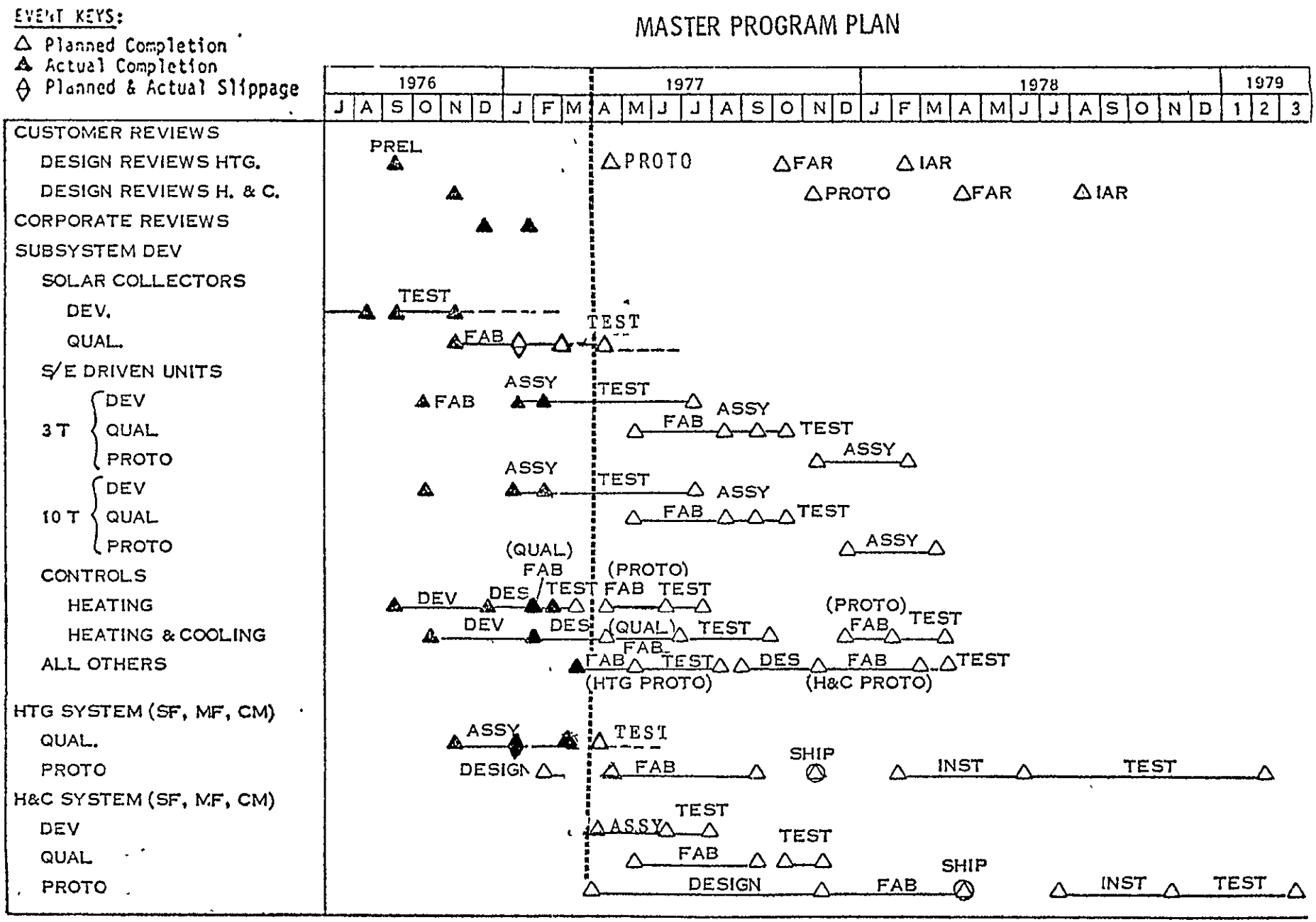

Figure 3-1. M :er Program Plan

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MASTER PROGRAM PLAN

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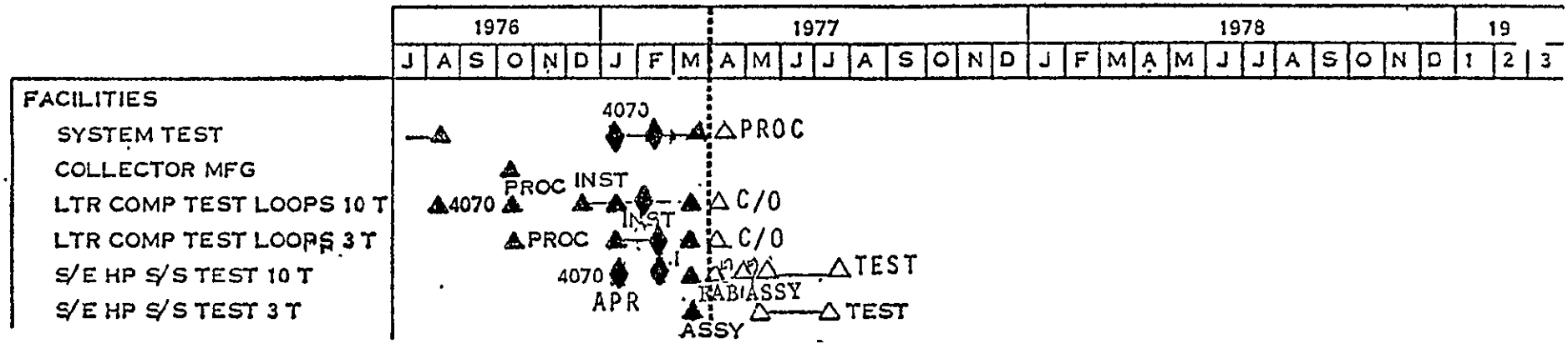

Figure 3-1. Master Program Plan (Cont)

The heating only system test was installed and checked out. Initial tests were run.

In the facilities area approval was obtained to construct the system test stands, the subsystem test stands, and the second set of component test loops. Approval of the collector manufacturing facility was imminent but not yet accomplished.

Figure 3-2 is the schedule for the WBS elements. The activity associated with heating only prototype hardware will be rescheduled when sites are identified.

Figure 3-3 shows the data deliveries.. During this period all scheduled items were delivered.

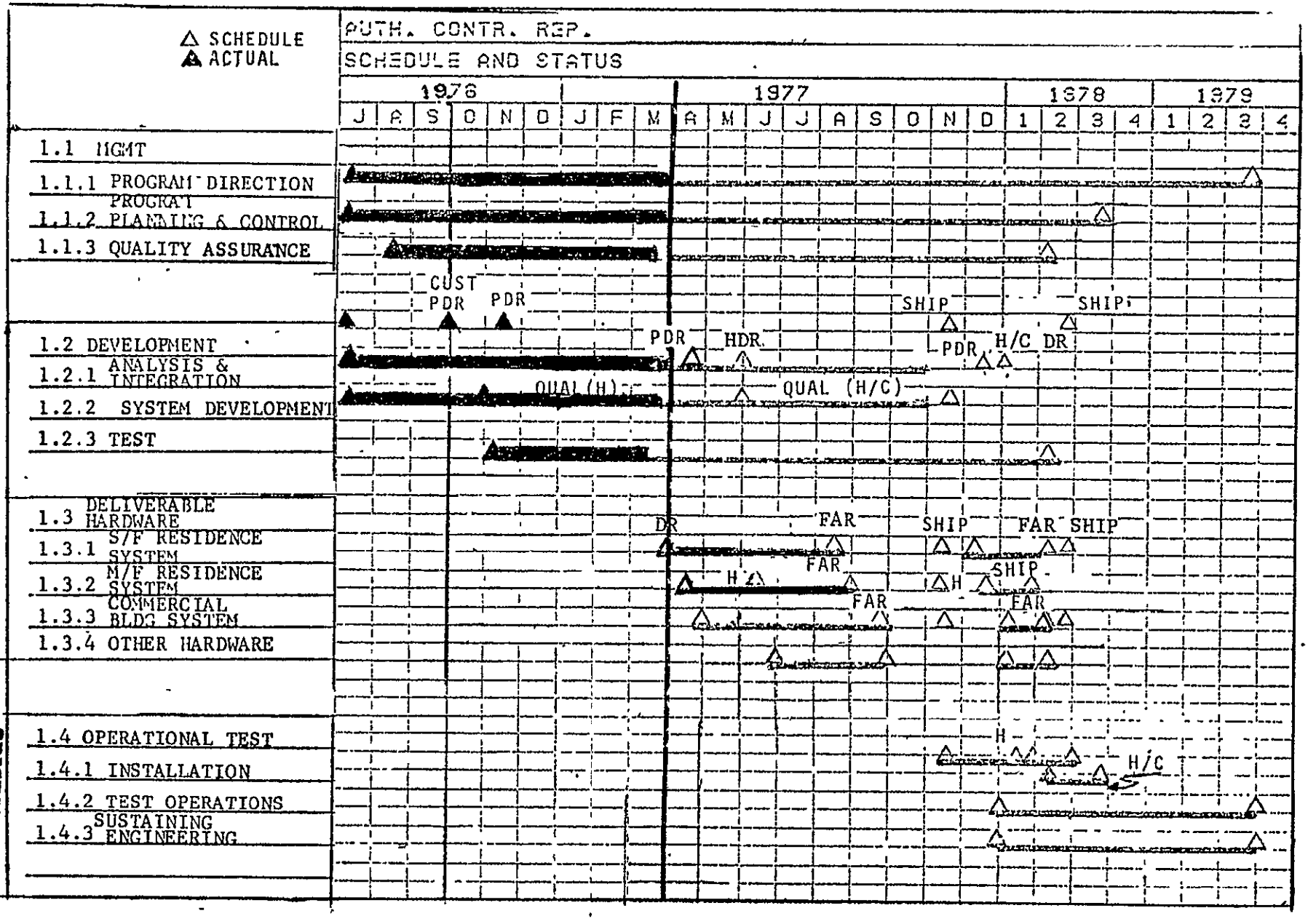

Figure 3-2. WBS Element Schedule and Status

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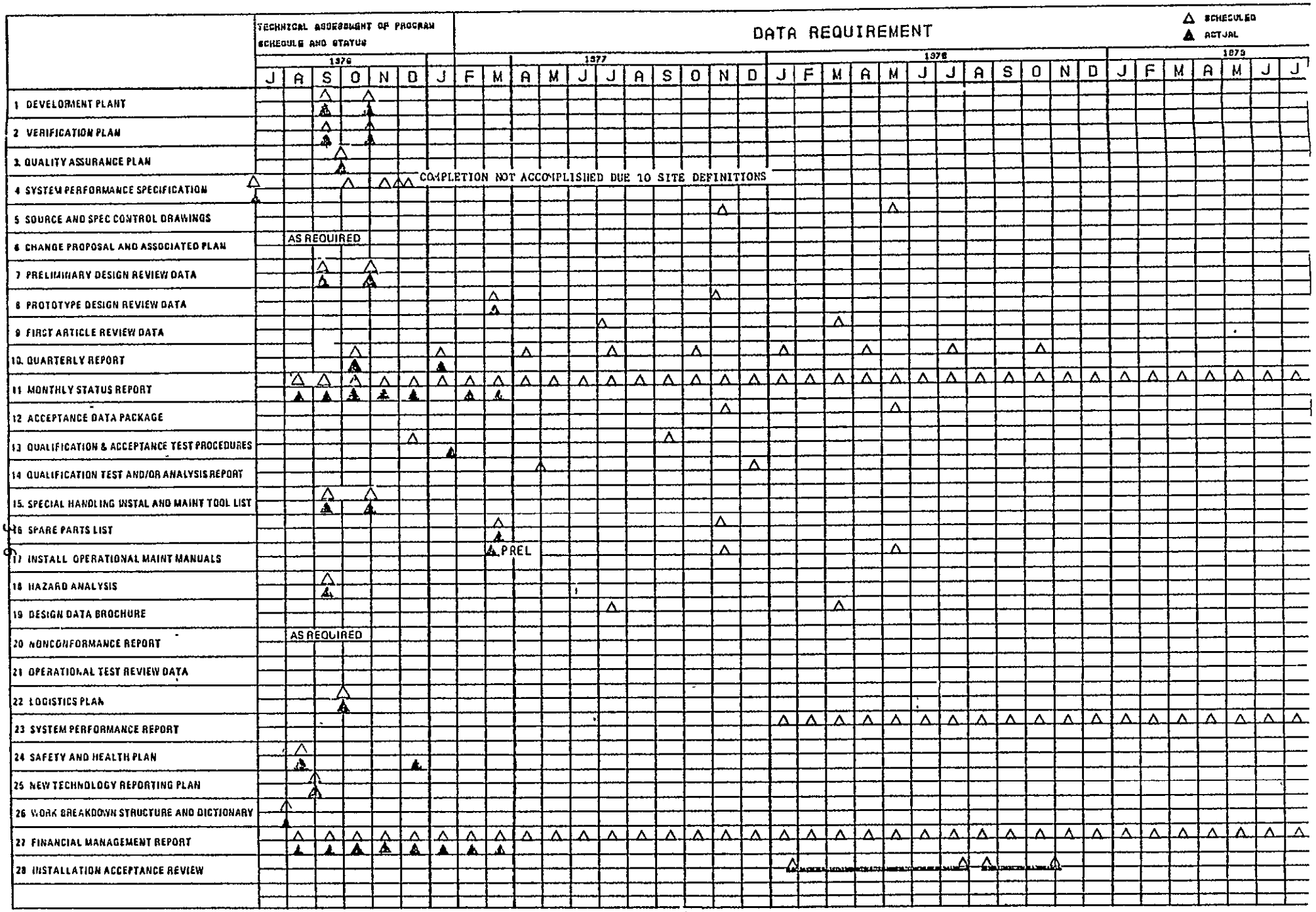

Figure 3-3. Data Requirements Status

PART IV

TECHNICAL PERFORMANCE

SECTION 1

TASK 1.1 - MANAGEMENT

1.1 PROGRAM DIRECTION (WBS 1.1.1)

During this period program operation continued in the manner established during the initial quarter. The program team, shown in Figure 1.1-1, is essentially the same as the one established in the first period and modified slightly during the second period.

Major customer coordination events included a quarterly review in January (19 & 20) and an informal review at Valley Forge on 1/27/77. Late in the period a meeting involving ERDA was scheduled for April 4 and 5. It is anticipated the results from the December 6 presentation at NASA Headquarters will be incorporated into the program early the next period.

Internal General Electric meetings included the first session of the Corporate Review Board on January 28 and an internal program review with upper management on March 4. Late in this period (March 31) a corporate team reviewed the solar collector design and development status.

1.2 PROGRAM PLANNING & CONTROL (WBS 1.1.2)

1.2.1 Program Control

The basic program control tool being used on this program is the control room. It was used during this period to schedule key milestones and program activities and monitor their status. This control room represents the official program schedule against which GE's technical status and progress is monitored. The scheduled data

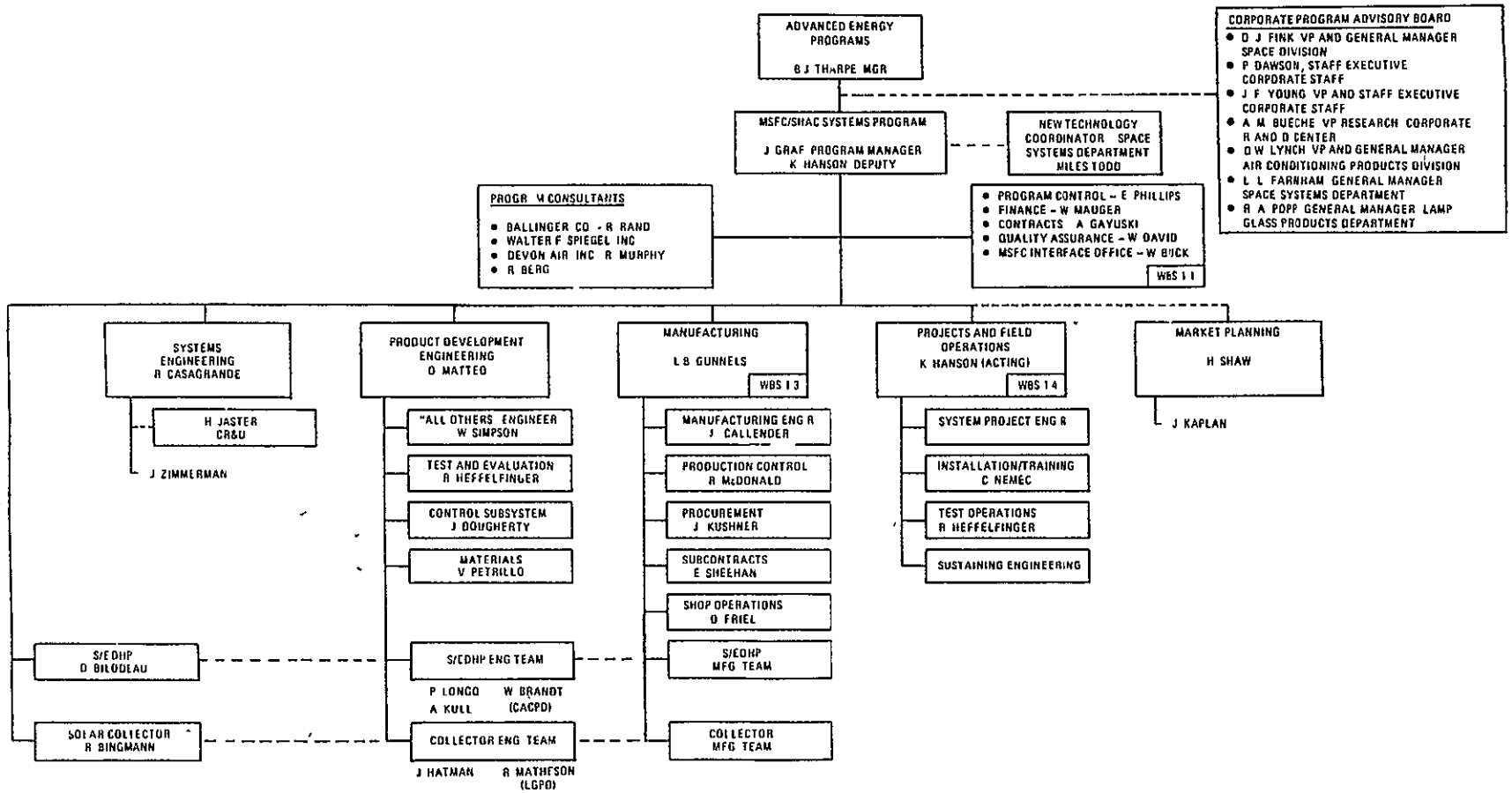

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Figure 1.1-1. Program Organization

required for the monthly, quarterly and management reports is extracted from the control room posting. The schedules in the control room include an overall program summary and with detailed task schedules on the side walls. The individual task sections of the control room schedules are monitored and maintained by the responsible task leaders. Daily program status meetings are held to follow hardware items. Problems involving interactions are identified and resolved at these meetings by the assignment of action items which are posted and monitored in the control room.

In the budgets area the program was monitored on the basis of the profile presented in the first quarterly report. Overall budget results are posted in the control room and available on a continuing basis for inspection by management. A cost review exercise is currently underway with results to be presented in the next quarterly report.

1.2.2 Data Management

The scheduled data submittals completed during this period were as follows:

Data Requirements No.	
- 3	Quality Assurance Plan (Change 1)
-10	Quarterly Report
-11	Monthly Status Reports (2)
-13	Qualification Test Procedures Solar Integrator Solar Collector Heating System Control
-26	Financial Management Report (2)

In addition responses were provided on list of comments generated by Mr. Rooks, ERDA consultant.

As of this date 1 RID is still outstanding from the PDR's.

1.2.3 Change Control

The status of Change Proposals is as follows:

CP001 - Approved with exception of 001-6

CP002 - Cancelled

1.3 Quality Assurance (WBS 1.1.3)

Change 1 to revision A of the Quality Assurance Plan was released this period. The change incorporates the new nonconformance reporting form to be used on the SHAC Program. Notification of approval was received from MSFC.

Significant Quality Assurance activities:

1. Early in this period, the AFPRO Quality Assurance Plan for SHAC surveillance was approved by MSFC and a meeting was held between AFPRO representatives and GE quality personnel to familiarize them on Program purpose, status and hardware and facility. It was evident in reviewing the AFPRO plan and the GE plan that there were possible areas of inconsistencies between the two. These areas were discussed and progress toward mutual understanding reached.
2. Qualification test policy was established and qualification test plans were approved for the Collector, Conrols and Heating system.
3. Quality Assurance has been working closely with both Engineering and Purchasing to develop a qualified vendor as a second source for solar tube coating application.

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SECTION 2

TASK 1.2 - SYSTEM DEVELOPMENT

2.1 INTRODUCTION

The major program activity this period included the start of the test program in the S/E DHP development and in refinements of the heating-only systems in preparation for the Prototype Design Review. Operational test site activities have begun and the Ft. Meade site design activities are underway. Key results of these activities are presented in this section organized by WBS elements.

2.2 ANALYSIS AND INTEGRATION (WBS 1.2.1)

System analysis activities were directed toward refining the heating system parameters. Trade studies have been performed to support hardware selections for all systems and for the heating-only operational test sites in particular. The heating system qualification tests were supported by predicting qualification test component performance prior to conducting the test. Details of the test can be found in Section 2.4.

2.2.1 BASELINE SYSTEM CONFIGURATIONS (HEATING-ONLY SYSTEMS)

The heating-only baseline systems have been upgraded through changes in the modes of operation. The solar collectors are prevented from reaching stagnation temperatures by using the heat dump whenever collected solar energy exceeds the capability of the system to make use of it. Stagnation now will occur only when there is a power failure or a Pump P1 failure.

The use of the heat dump mode has caused a re-evaluation of the primary solar collection loop. It was decided to and a by pass around TKX1 such that there will be no flow through the tank under normal conditions. This feature allows the tank to run cool which allows the use of a smaller tank and eliminates the requirement for insulation. The system schematics reflecting this change are shown in Figures 2.2-1 through 2.2-3.

The system controls have changed through the elimination of a differential temperature control setting to enable the solar loop pump to turn on. Instead, the solar integrator alone is used to turn the system on. When the solar integrator senses an insolation rate greater than 35 BTU/hr-ft^2, the solar collection loop will activate. After a small time delay, the storage loop pump will activate. This control scheme is far simpler than using differential temperature controllers. A trade study describing that only a 1% penalty occurs using this approach is presented in Section 2.2.3.

2.2.2 BASELINE SYSTEM CONFIGURATIONS (HEATING AND COOLING SYSTEMS)

In this reporting period, there have been no new system level configuration changes for heating and cooling systems outside of the change in the solar collection loop. The bypass around the TKX 1 tank was incorporated for the heating and cooling systems as well since the collector loop is common to all of the GE system configurations. The system schematics for the HCSF, HCMF, and HCCOM systems are presented in Figures 2.2-4 through 2.2-6.

2.2.3 SYSTEM TRADE STUDIES

2.2.3.1 TES TANK SIZE OPTIMIZATION

The optimum TES size is defined from simulations of the solar

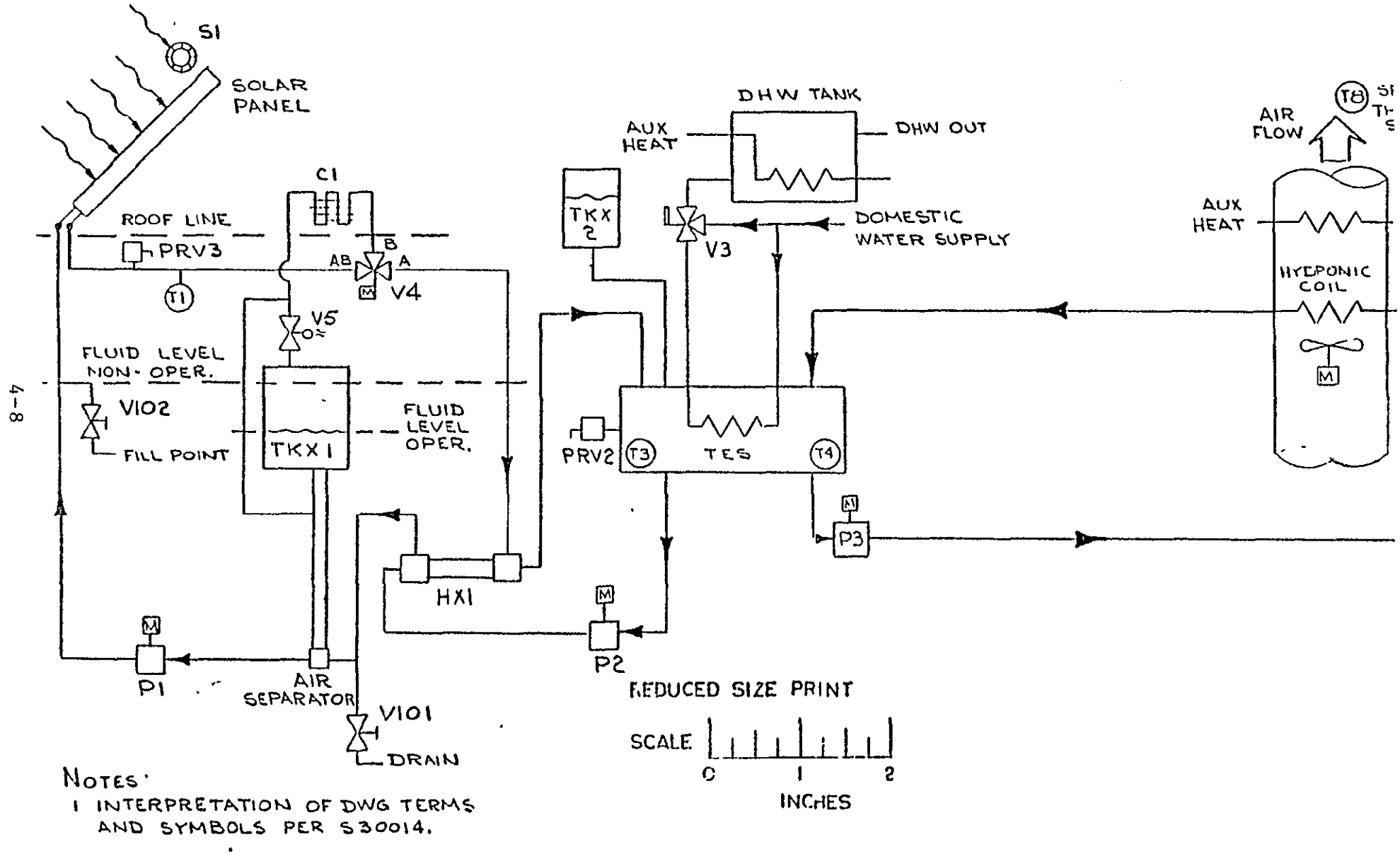

Figure 2.2-1. System Schematic-HSF

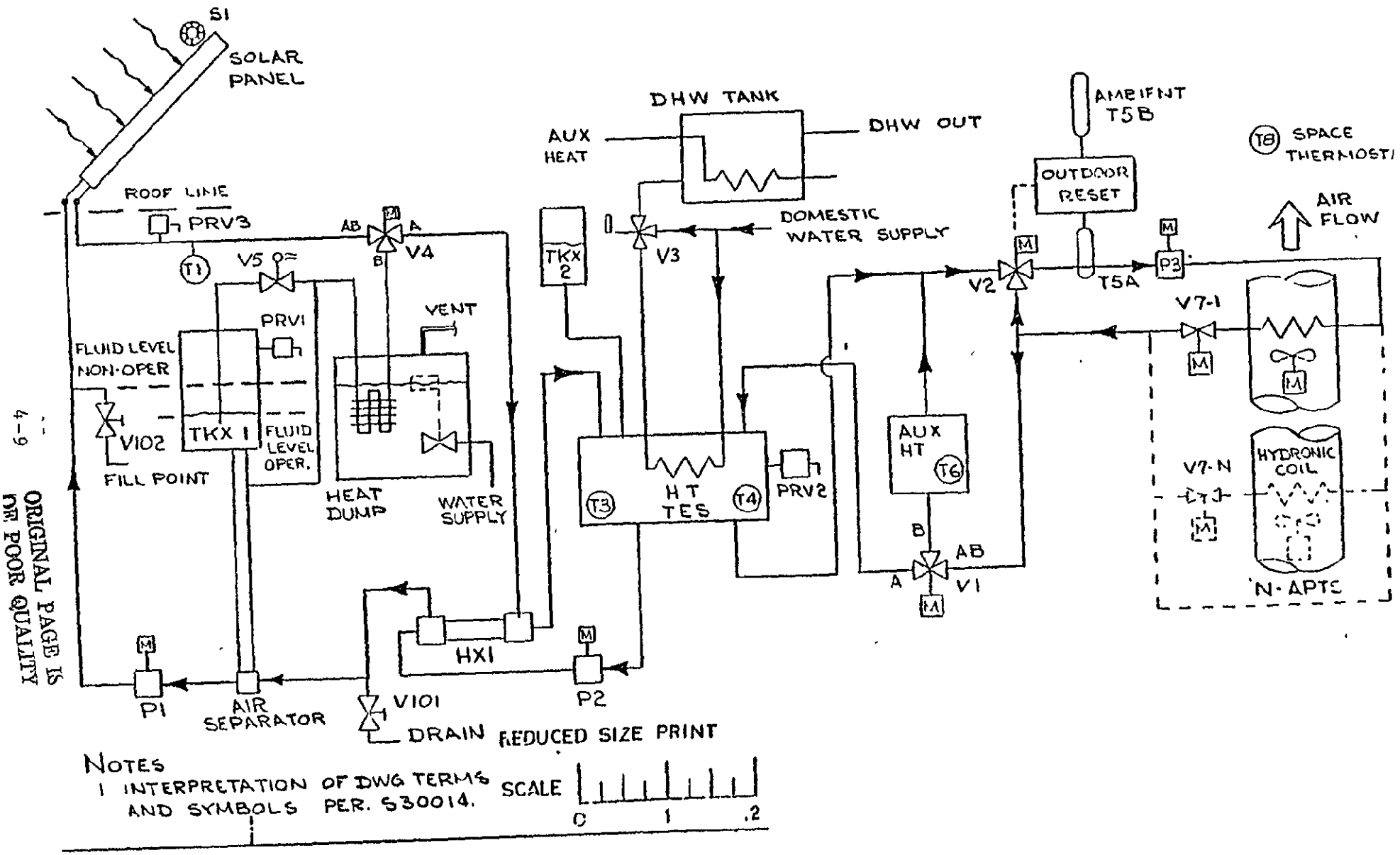

Figure 2.2-2. System Schematic-HMF

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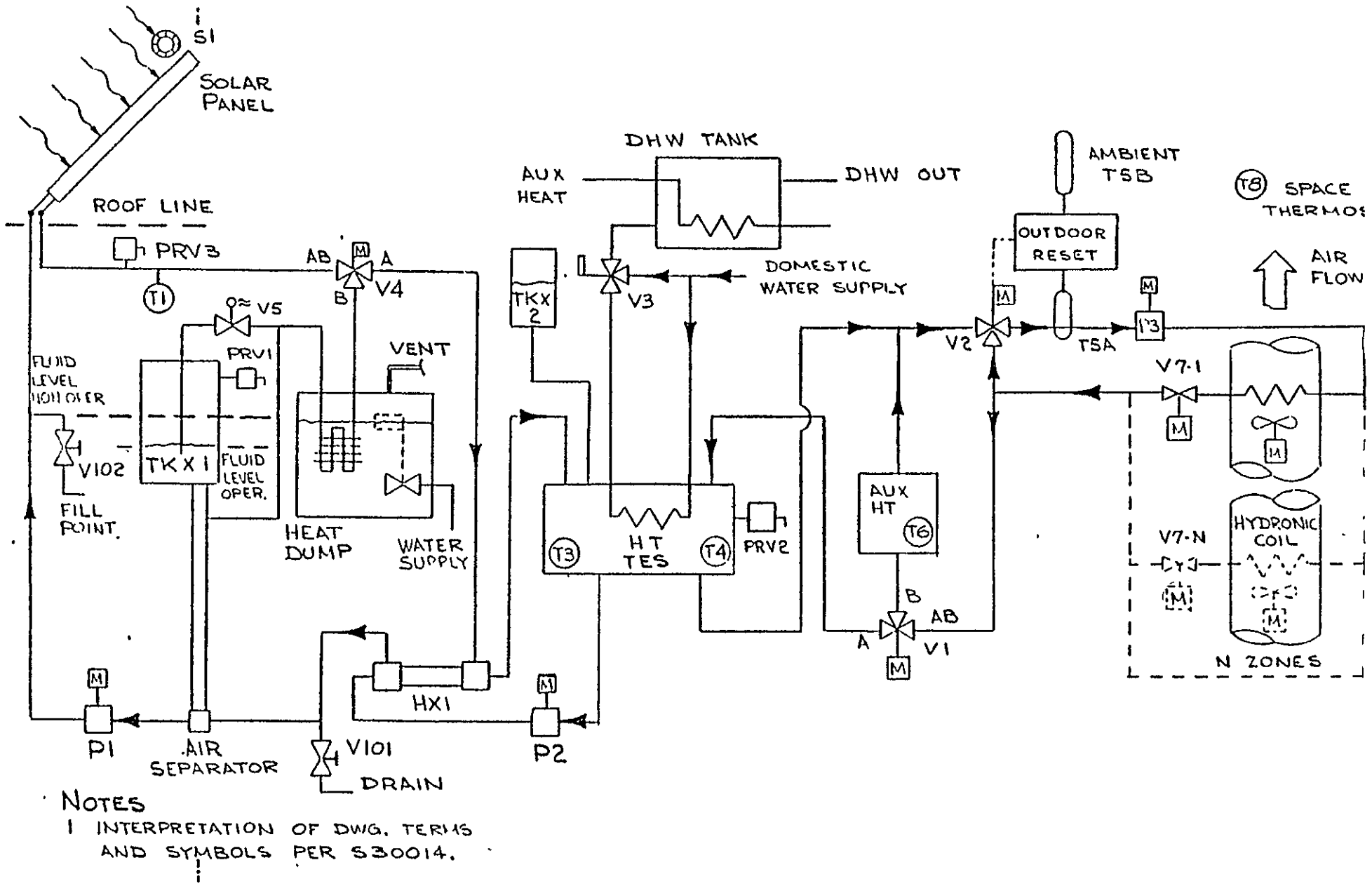

Figure 2.2-3. System Schematic-HCOM

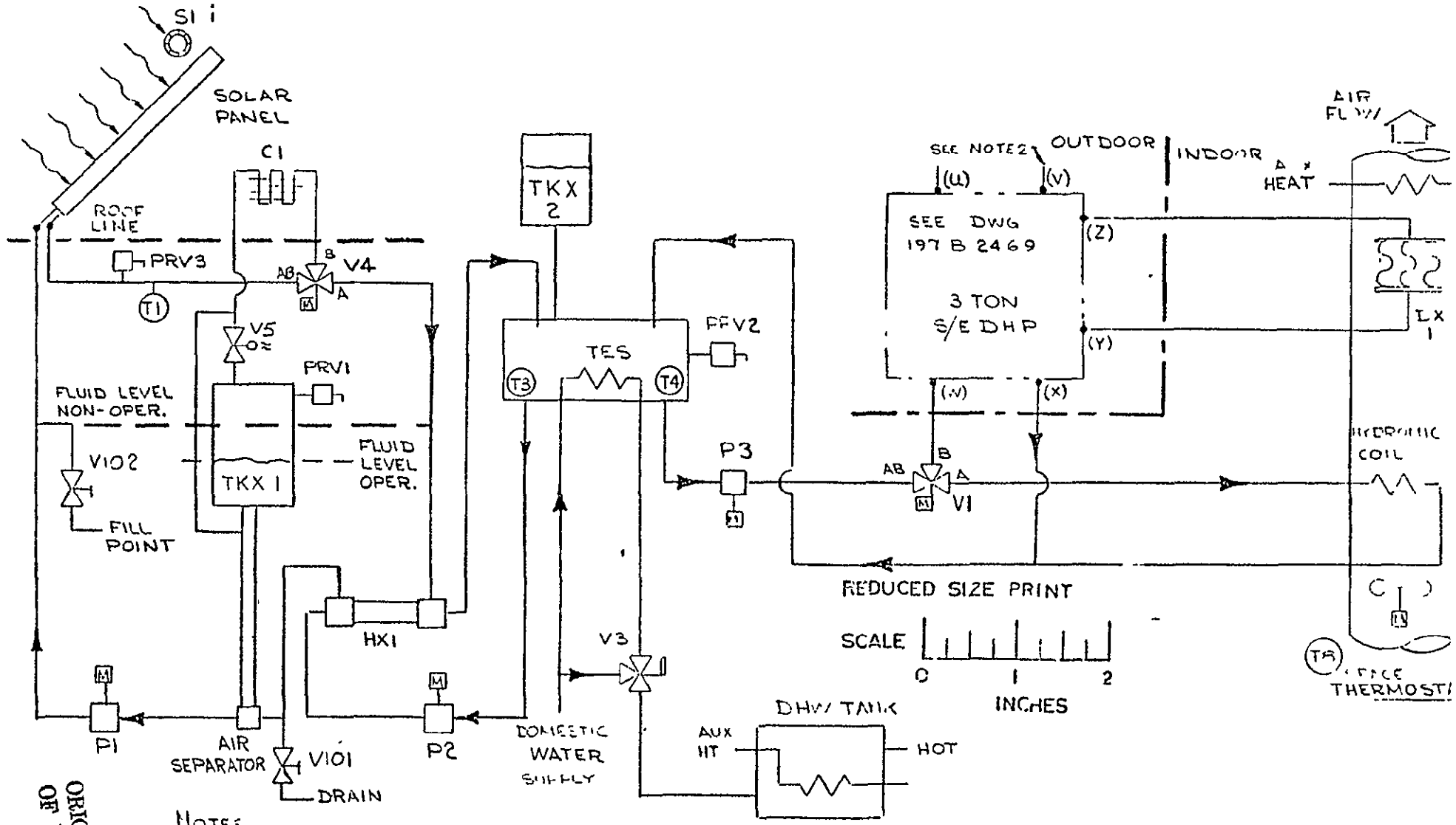

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Figure 2.2-4. System Schematic-HCSF

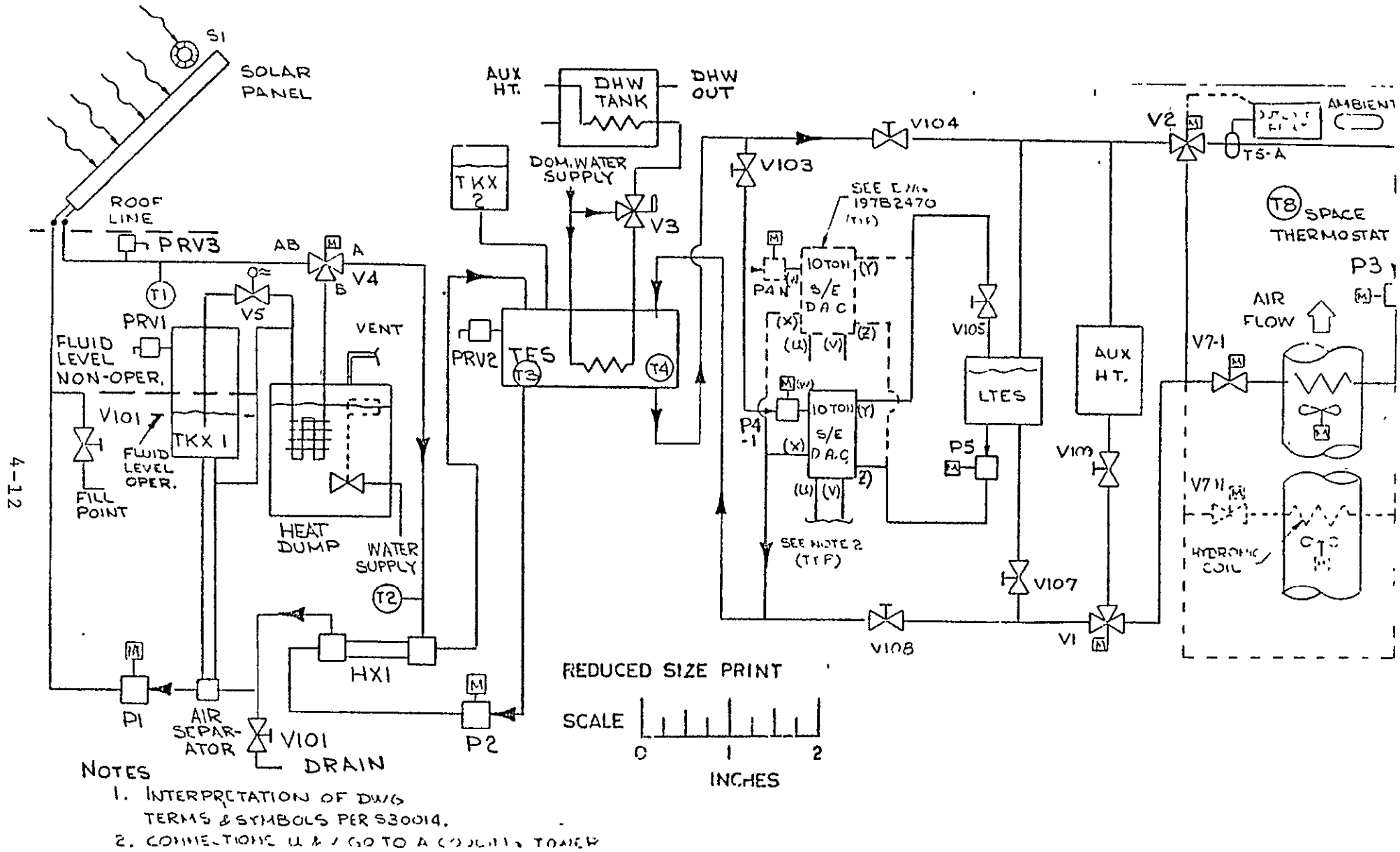
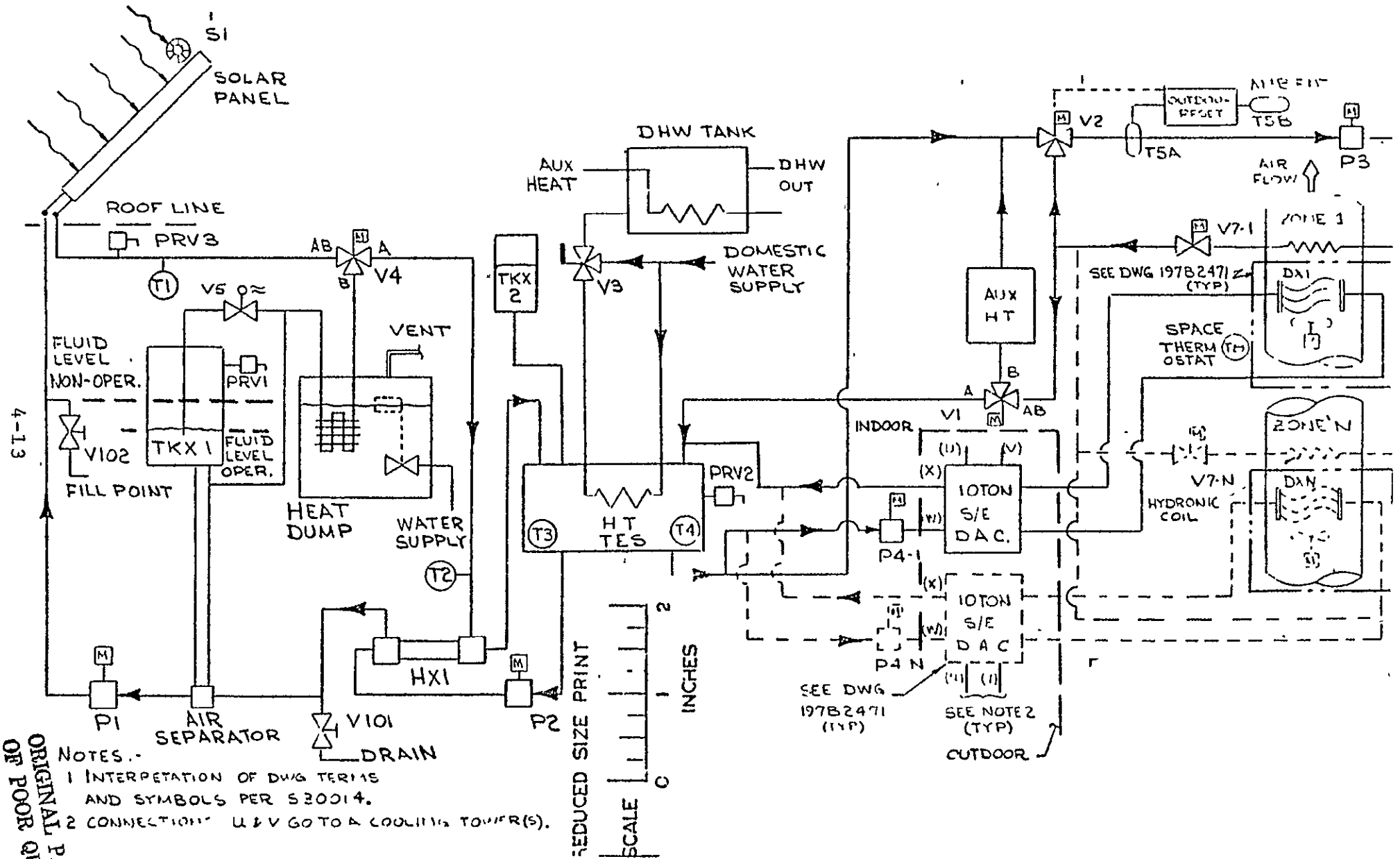


Figure 2.2-5. System Schematic-HCMF



Fiogure 2.2-6. System Schematic-HCCOM

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system performances in Washington, D.C. and Madison, WI. single family residences, which meet the ASHRAE 90-75 standards. As shown in Figure 2.2-7, when the TES volume is reduced below 1.0 gallons/ft^2, the system performance starts to decrease at an appreciable rate. Increases in capacity above this value do not produce significant improvements in performance.

Variations of the maximum allowable TES temperature were also examined and are shown in Figure 2.2-7a. The seasonal system performance can be increased, as shown by the single date point in Figure 2.2.7a, by increasing the size of the domestic hot water coil. When the TES tank maximum temperature is decreased to 180°F, the storage capacity has to be increased by 50% to maintain the same system performance with an oversized domestic hot water coil. The cost of an ASME pressure vessel is 30% greater than a standard tank. Therefore, the system using the higher maximum TES temperature system, having a storage capacity of 1.0 gallons per square foot of collector area, is more cost effective.

2.2.3.2 SOLAR LOOP HEAT EXCHANGER

The solar loop heat exchanger has been optimized for the heating-only system in accordance with the procedure developed during the previous reporting period.

Results of the study are presented in Figure 2.2-8 along with the previous results developed for the heating and cooling systems. The heat exchanger size requirements of the heating-only system are approximately one half those of the heating and cooling system.

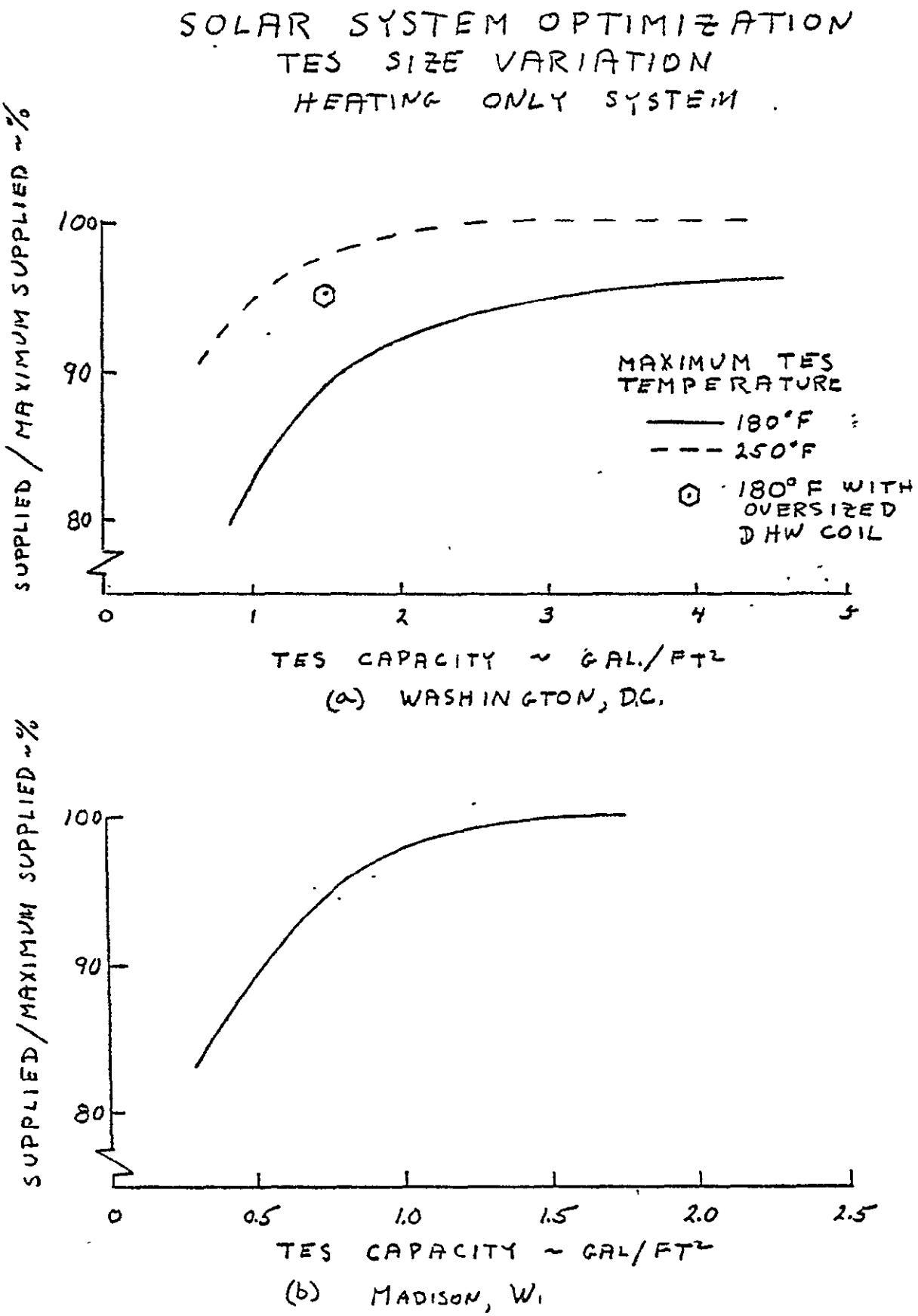

Figure 2.2-7 SOLAR SYSTEM OPTIMIZATION TES SIZE VARIATION HEATING ONLY SYSTEM

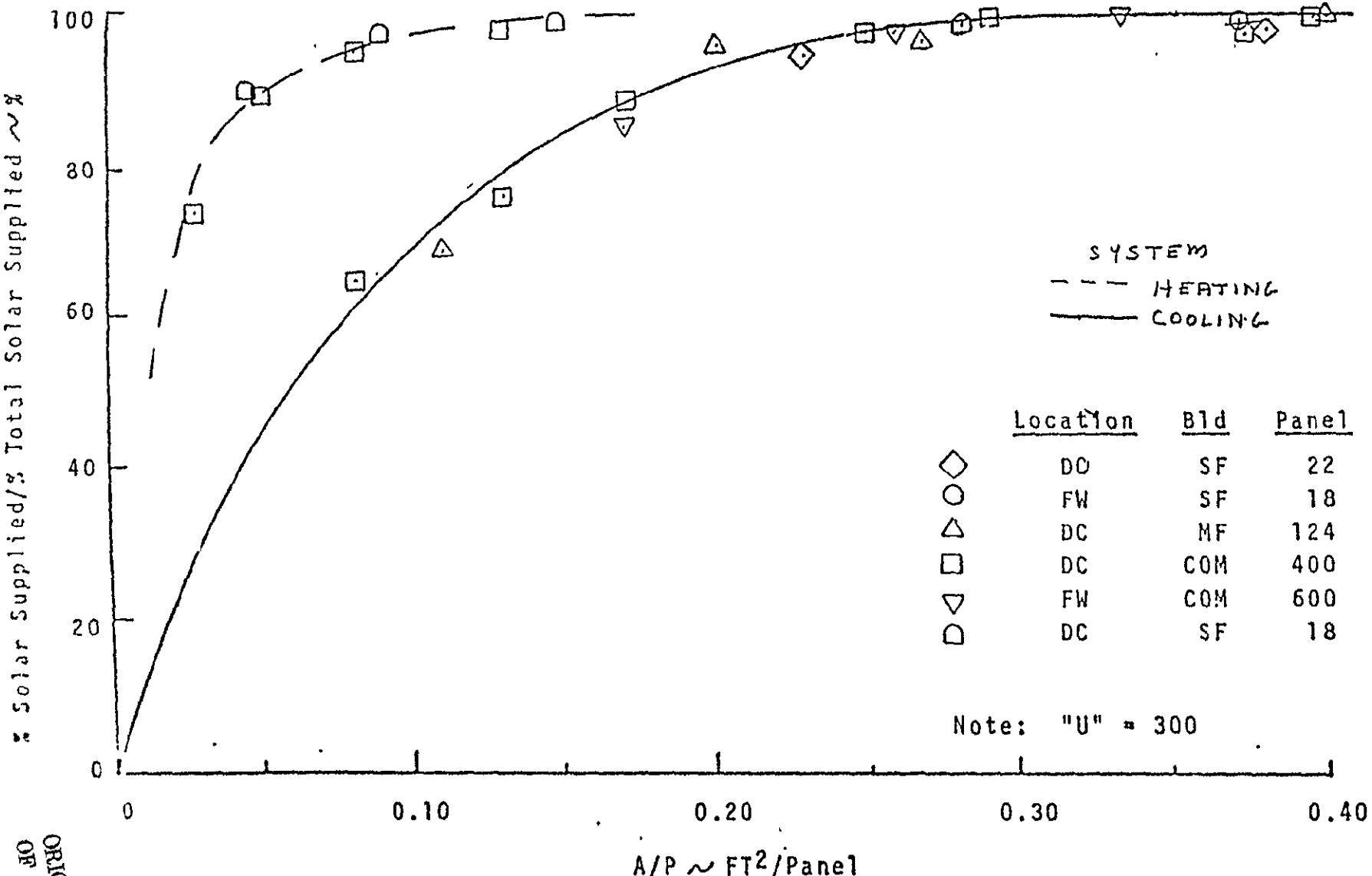

Figure 2.2-8 NORMALIZED SYSTEM PERFORMANCE

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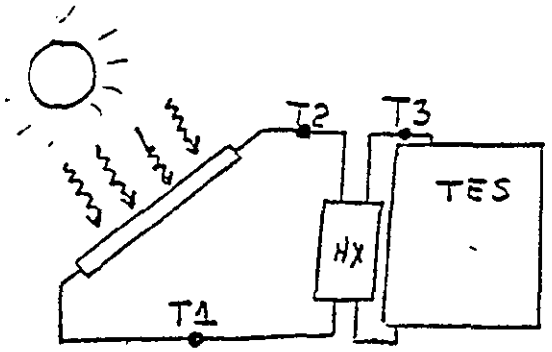
2.2.3.3 SYSTEM INSULATION

The solar system components, being at a higher than ambient temperature, will require some insulation to limit the energy loss from the system. The amount of insulation which should be applied to the system was defined as the most economical thickness using a comparison of the cost of insulation and the value of the collected solar energy. An economic analysis procedure developed by the York Research Corp. (Ref. 2.2-1), was applied to the two locations (Fort Worth and Washington, D.C.) and the three building types (Single Family, Multi-Family and Commercial).

The insulation requirement will be defined using the average temperature difference which exists between solar fluid and the environment. Due to the Cyclic nature of a solar system, one temperature cannot be readily specified as the average solar fluid temperature. Accordingly, several solar system simulations were made using the three basic building types at both locations and the number of hours that the component was at various temperature levels were recorded. Also, selected temperature differences were defined on an hourly basis. Table 2.2-1 presents a typical temperature history which a solar system is predicted to experience. This table indicates the number of time periods (one-hour periods) that the component temperature is within a specific temperature band.

The yearly energy loss can be determined by summing the incremental heat losses. When a constant U value is defined, the yearly

TABLE 2.2-1 SYSTEM TEMPERATURE



TAM = $T_{AMBIENT}$ (DRY BULB)

D1 = T1 - $T_{AMBIENT}$

D2 = T2 - $T_{AMBIENT}$

D3 = TIN - $T_{AMBIENT}$

D4 = T3 - T_{ROOM}

D5 = TES - T_{ROOM}

TAM — over 1 column

T	T1	T2	TES	D1	D2	D3	D4	D5
1	0	0	0	0	0	0	0	0
4	0	0	0	5	0	0	0	0
9	0	0	0	13	0	0	0	0
14	0	0	0	37	0	0	0	0
19	0	0	0	106	0	0	0	11
24	0	0	0	324	0	0	0	267
29	0	0	0	392	3	2	3	175
34	0	0	0	732	4	0	5	141
39	0	0	0	737	24	10	25	35
44	0	0	0	755	57	47	120	60
49	0	0	0	724	37	76	245	68
54	0	0	0	536	50	68	208	58
59	0	0	0	724	112	60	284	77
64	0	0	0	815	127	103	285	57
69	0	0	0	741	124	82	262	76
74	0	0	0	261	115	107	253	66
79	0	0	0	555	102	82	207	80
84	0	0	0	353	86	77	133	73
89	3	0	4	186	103	89	194	65
94	173	74	477	47	102	79	231	59
99	301	220	835	6	75	104	233	49
104	124	113	245	0	92	93	204	44
109	104	117	203	0	59	76	173	50
114	64	89	161	0	78	77	210	50
119	69	62	164	0	72	76	207	86
124	58	61	146	0	71	84	134	88
129	70	65	156	0	120	106	252	89
134	74	61	163	0	173	115	327	148
139	51	63	145	0	207	159	490	140
144	71	54	173	0	203	157	462	173
149	71	74	166	0	132	206	455	177
154	79	77	196	0	196	176	465	195
159	71	83	156	0	201	170	361	169
164	57	76	157	0	209	176	366	147
169	47	72	128	0	201	184	477	220
174	43	66	123	0	190	194	499	192
179	40	45	100	0	119	183	445	144
184	46	49	130	0	71	134	229	99
189	73	57	146	0	29	127	146	1
194	74	71	151	0	16	89	55	0
199	66	65	171	0	3	70	12	0
204	91	89	199	0	2	39	2	0
209	135	70	329	0	0	7	0	0
214	144	116	479	0	0	5	0	0
219	155	124	381	0	0	0	0	0
224	205	146	448	0	0	0	0	0
229	195	154	463	0	0	0	0	0
234	193	187	518	0	0	0	0	0
239	147	175	479	0	0	0	0	0
244	193	153	497	0	0	0	0	0
249	399	152	511	0	0	0	0	0
254	0	209	0	0	0	0	0	0
259	0	145	0	0	0	0	0	0
264	0	96	0	0	0	0	0	0
269	0	35	0	0	0	0	0	0
274	0	54	0	0	0	0	0	0
279	0	3	0	0	0	0	0	0
284	0	0	0	0	0	0	0	0
289	0	0	0	0	0	0	0	0
294	0	0	0	0	0	0	0	0
299	0	0	0	0	0	0	0	0

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energy losses can be expressed in terms of an energy loss factor (ELF) as defined below:

$$ELF = \sum_{T} t * \Delta T.$$

The system component energy loss per unit area for the period of time in question is obtained by multipling the ELF by the average heat transfer coefficient, U.

Table 2.2-2 presents the ELF values for the three building types at two geographical locations over a one (1) year time period. The difference between the values of the different buildings at the same location are very small for each component.

TABLE 2.2 -2

Energy Loss Potential

ELF Values

Site	Bldg.	Collector Components	Tank Components	Collector Components	Tank Components
Washington	SF	0.46	0.92	0.25	0.49
	MF	0.46	0.92	0.27	0.53
	COMM	0.49	0.96	0.29	0.57
Forth Worth	SF	0.51	1.14	0.22	0.52
	MF	0.53	1.16	0.23	0.56
	COMM	0.54	1.23	0.25	0.62

Note: All values $hr\text{-}^{o}F*10^{-6}$

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The optimum insulation thicknesses defined using the econonic analysis procedure are presented in Figures 2.2-9, 10 and 11 for flat surfaces and pipes. The optimum insulation thickness increases with increases in fuel costs and decreases in installed insulation costs.

In general, the factory applied or simplified kit insulation packages should cost between $1.25 and $2.50 per square foot per inch thickness. Site installed costs will be larger and strongly related to local conditions.

The solar system simulation computer code was used to define the variation in total system performance with variations in insulation thicknesses. The optimum insulation thicknesses are presented below for each application. This is based on the characteristic price of fuel in 1985 and the installation costs associated with that price assuming a constant inflation rate.

Application Location	Heating Only	Heating and Cooling
Storage	1.5"	3.0"
Pipes	1.0"	1.5"

2.2.3.4 INSOLATION RATE SENSOR

The solar system will start the collection process when the insolation rate reaches a pre-determined level. This level is defined such that the system does not lose significant amounts of energy by starting too soon or too late. If pump P1 starts too early, energy will be lost from the system and power will be expended by the collection loop pump without collecting energy.

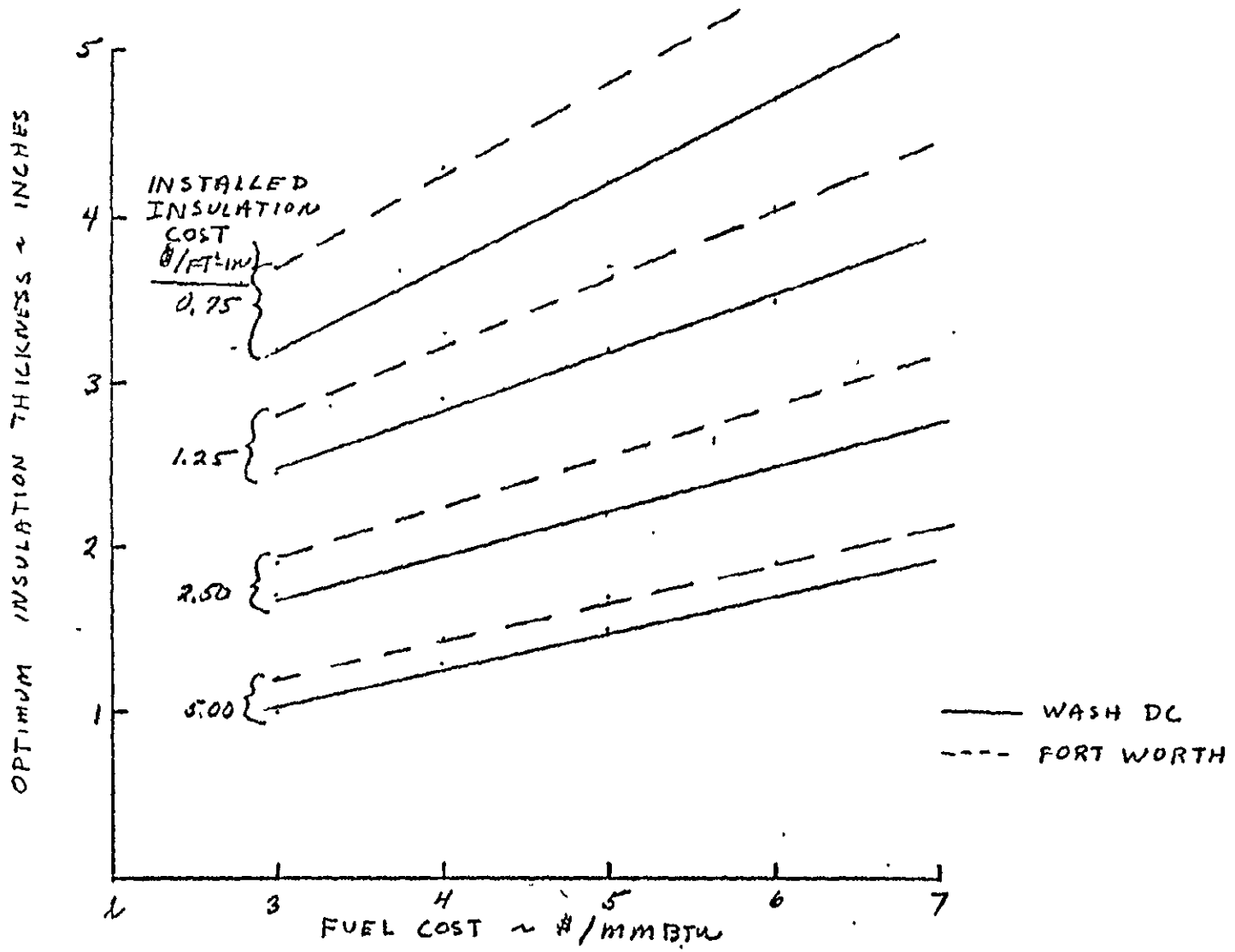

Figure 2.2-9 FLAT INSLUATION THICKNESS REQUIREMENTS HEATING AND COOLING APPLICATION

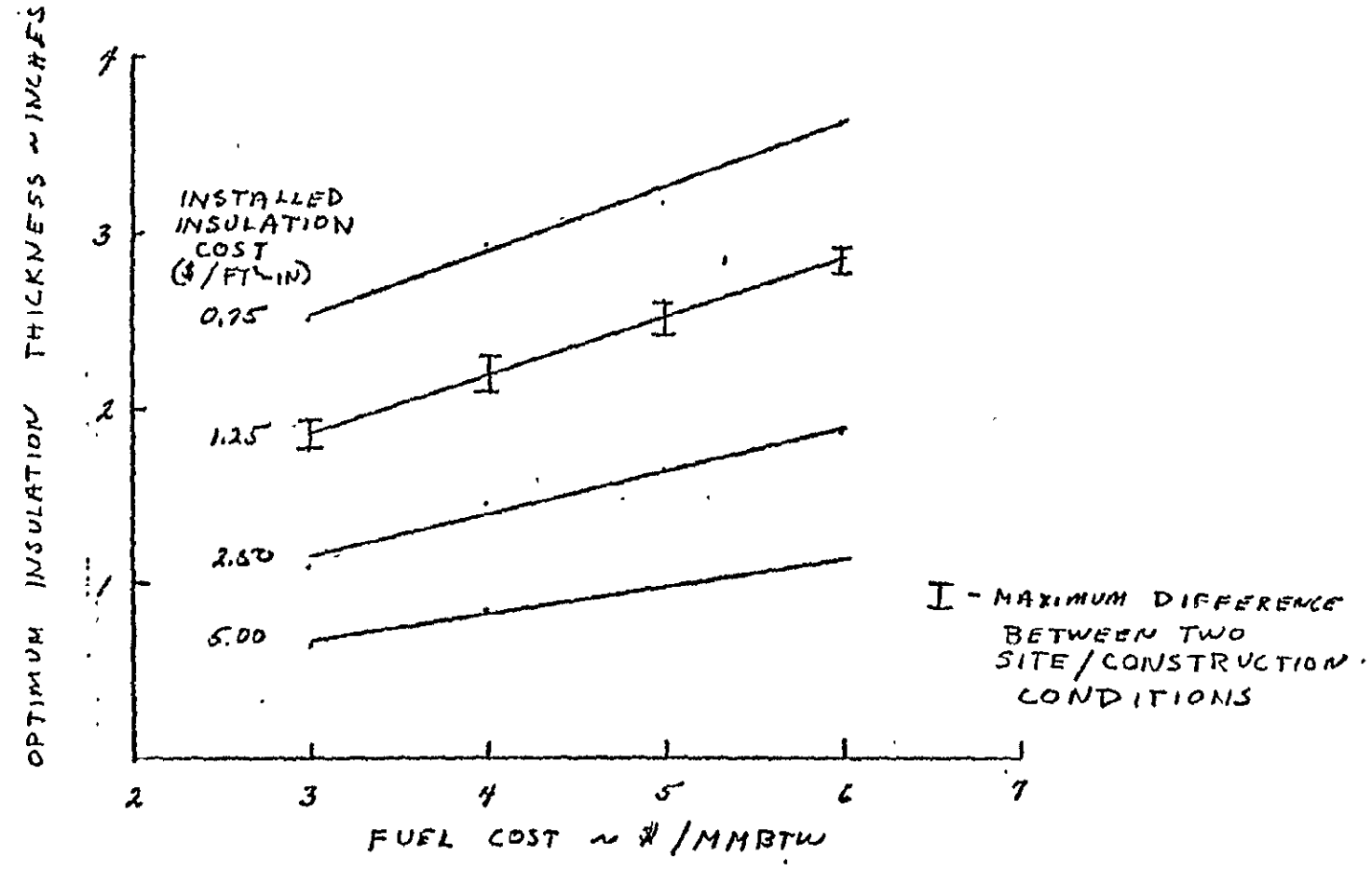

Figure 2.2-10. FLAT INSULATION THICKNESS REQUIREMENTS
HEATING ONLY APPLICATION

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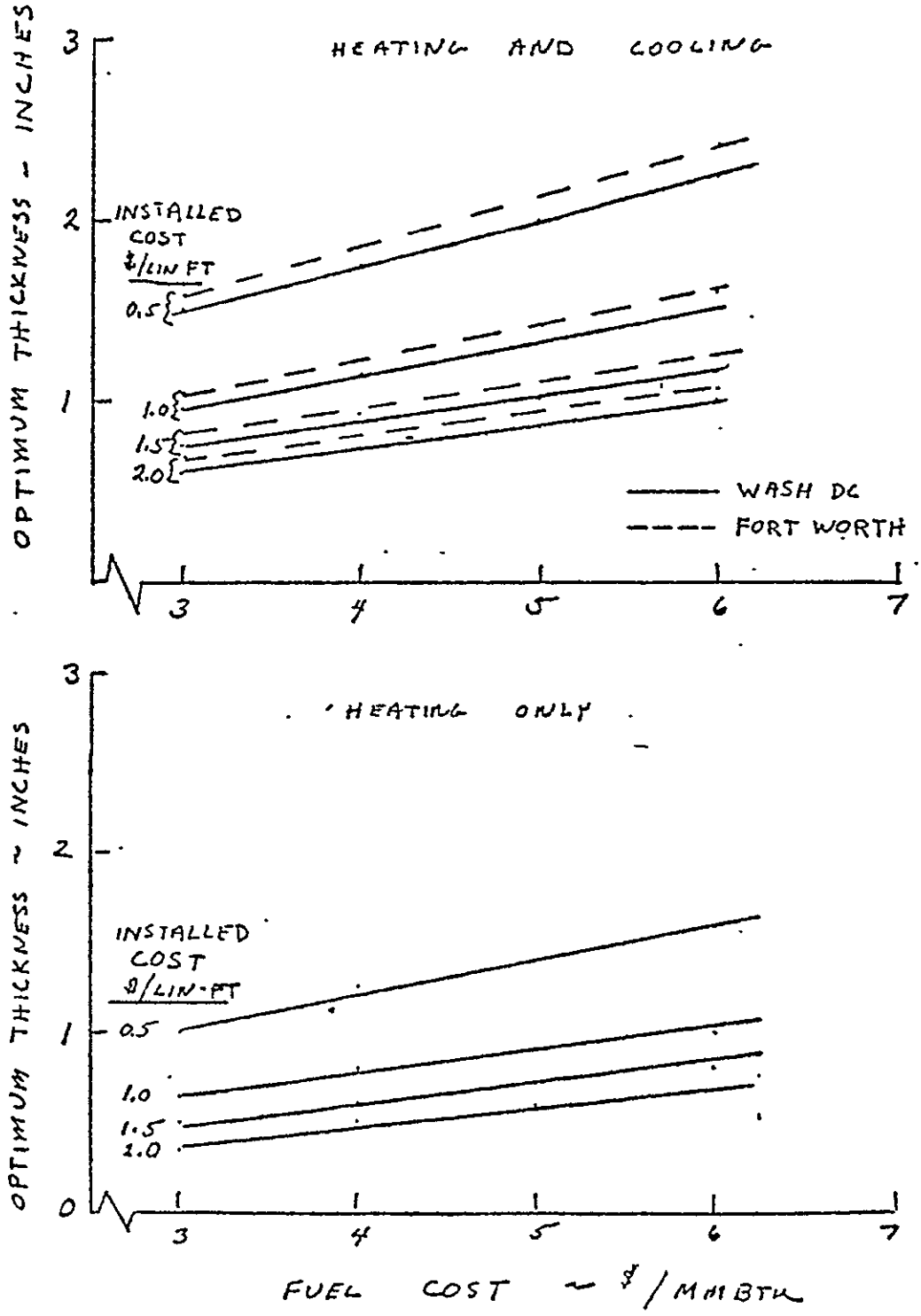

Figure 2.2-11. PIPE INSULATION REQUIREMENTS

When the system is started too late, collectable energy will not be collected by the system.

A detailed analysis was conducted to define the optimum insolation rate at which to start the collection process. The exact value is not defined because the system will be starting at different temperatures during the year and will have loss rate which are directly proportional to the system temperature. Using a small timestep, solar system simulations were made with the collection process starting at various pre-defined insolation levels. As shown in Table 2.2 -3, the variation in system performance is not significant until the start insolation level exceeds 50 BTU/hr-FT^2. The optimum level should be between 20 and 35 BTU/hr-FT^2 on a tilted surface. The value chosen is 35 BTU/hr-FT^2. This value will allow for any system thermal capacitances which were not factored into the simulation.

TABLE 2.2 -3

PERFORMANCE CHARACTERISTICS

OF

DIFFERENT START-UP INSOLATION LEVELS

Incident Insulation BTU/FT^2-hr.	%Heating*	%Cooling*	%Total*
20	100	99	100
35	99	100	99
50	98	99	98
80	95	96	95

* Percent Solar supplied/maximum solar supplied

References:

4.2 "Economic Thickness for Industrial Insulation"
York Research Corporation, March 1976

2.3 SYSTEM DEVELOPMENT (WBS 1.2.2)

2.3.1 HEATING SYSTEMS (WBS 1.2.2.1)

2.3.1.1 Collector (WBS 1.2.2.1.1)

2.3.1.1.1 Collector Design & Performance Verification

The collector design is essentially frozen and all development testing complete. Glass handling problems in the field and several weak areas have been identified including poor pinch offs and assembly errors in the units.

Part of the design completion involved the capability of mounting collectors and integrating them into practical fluid management system. Both have been completed successfully.

Table 2.3.1.1.1-1 lists all of the development tests performed to date on the collector. No further development testing is considered necessary except for design changes that might be incorporated

The following charts, Figures 2.3.1.1.1-1 through 2.3.1.1.1-7 present a quick and cursory look at the design details.

Our testing objectives were to first, verify that our computer model for collector performance predictions was accurate since all our system sizing has been done by computer. We found the correlation to be excellent over the 6 hour period around solar noon. At the wider angles, we do see a variation. The variation has not been consistent, and therefore, a trend has not been identified other than we have noted a wide divergence in insolation reading on the pyronometers.

Table 2.3.1.1.1-1. Test Program Status

	TEST	COMPLETE	IN PROCESS	PLANNED
MATERIALS	GLASS			
	- THERMAL SHOCK	X		
	- WEATHER ABILITY	X		
	REFLECTOR			
	- INITIAL OPTICAL PROPERTIES	X		
	- STABILITY		X	
	FRAME CORROSION		X	
	INSULATION			
	- OUTGASSING	X		
	- MOISTURE PICKUP	X		
	- THERMAL CONDUCTIVITY	X		
	SHROUD SUPPORTS			
	- TEMP CAPABILITY	X		
	- UV RESISTANCE		X	
	FIN			
	- OXIDATION	X	X	
	COATING			
	- OPTICAL PROPERTIES	X		
	- TEMP STABILITY	X		
	- VACUUM STABILITY	X		
	- ADHERENCE	X		
	- REPEATABILITY	X		
	- ANGULAR DEPENDENCE		X	
SUBASSEMBLIES	SHROUD			
	- GETTER EFFECTIVITY	X		
	- LIFE		X	
	REFLECTOR			
	- EFFECTIVITY	X		
	- ORIENTATION SENSITIVITY	X		
	MANIFOLD			
	- THERMAL EXPANSION	X		
	- FIN EFFICIENCY	X		
	- PRESSURE DROP	X		
SYSTEM	PERFORMANCE			
	- INSTANTANEOUS EFFICIENCY	X		
	- DAILY EFFICIENCY	X		
	- "NO FLOW" SURVIVAL	X		
	- ANGULAR DEPENDENCY	X		
	STRUCTURE			
	- WIND LOADING	X		
	- MOUNTING	X		
	ADVERSE ENVIRONMENTS			
	- HAIL	X		
	- EMERGENCY SHUTDOWN SHOCK	X		
	SHIPPING AND HANDLING			
	- SHROUD SHIPMENT	X		
	- FRAME SHIPMENT		X	
	- MECHANICAL INSTALLATION	X		
	- HYDRAULIC INSTALLATION	X		
	COVER			
	- PERFORMANCE AFFECTS	X		
	- ENVIRONMENTAL SURVIVABILITY	X		
	- STABILITY	X		

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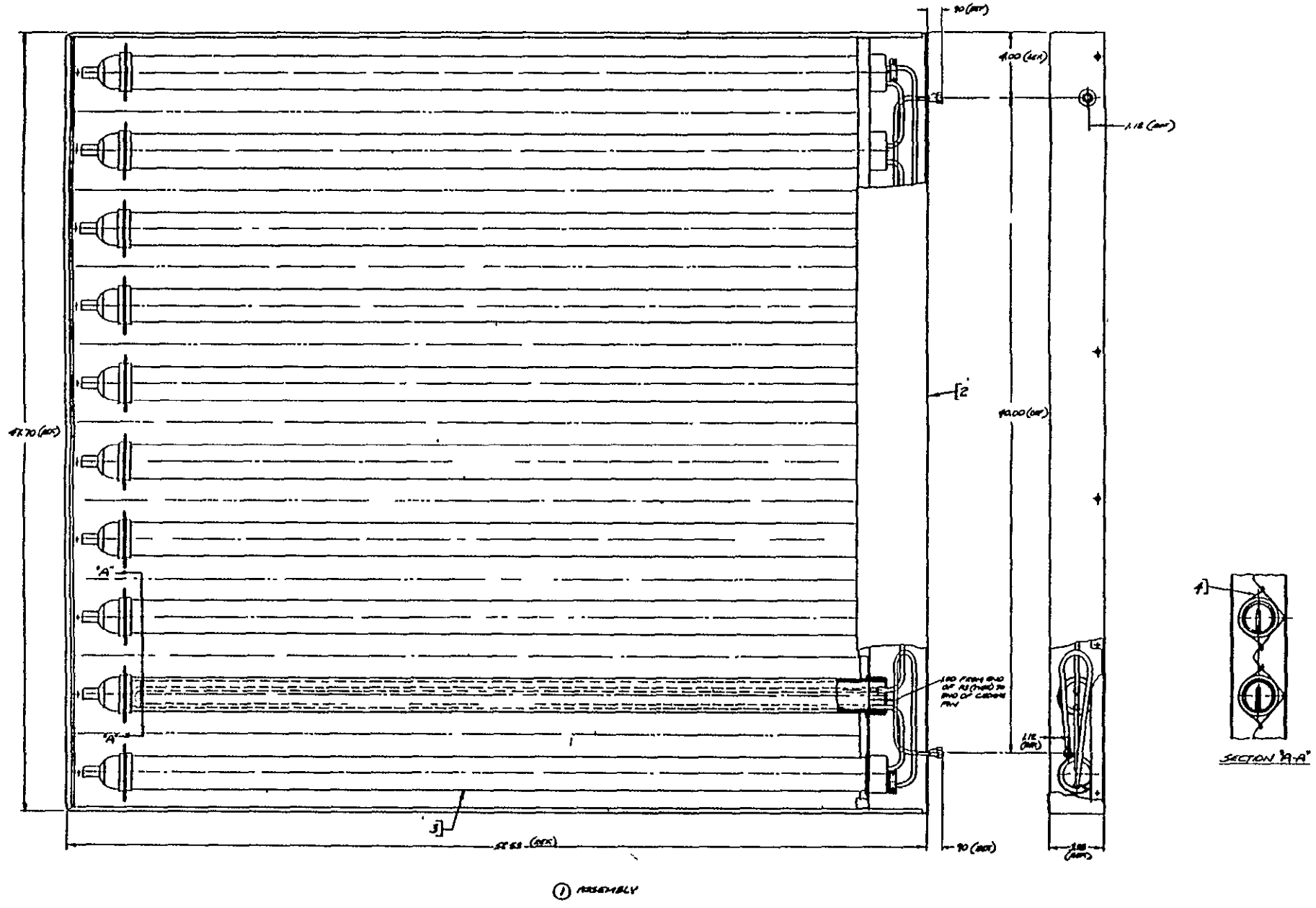
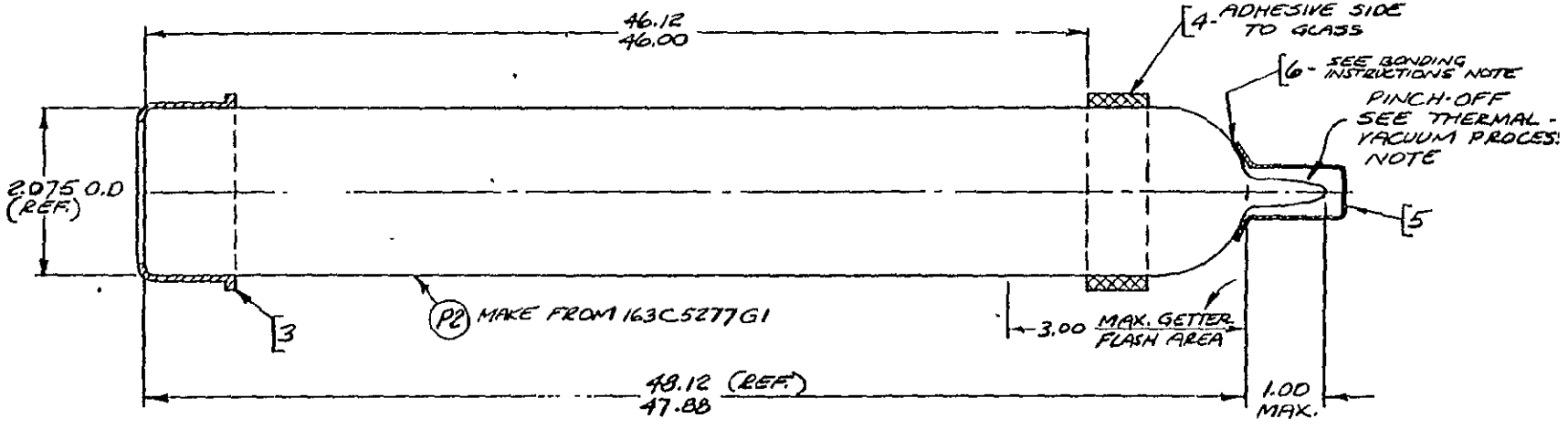


Figure 2.3.1.1.1-1. Collector Module Assembly

G1	PART NO	NAME	DRAWING NO DESCRIPTION MATERIAL WEIGHT
X	1	ASSEMBLY	
1	2	TUBULAR COLLECTOR	163C5277G1
1	3	GROMMET	273A6345P1
1	4	CUSHION STRIP	273A6018P1
1	5	THERMAL PROTECTOR	261A2704P1
AR	6	ADHESIVE	RAY-BOND R-84012, RM FRICTION MATERIAL CO.



G1 ASSEMBLY

BONDING INSTRUCTIONS (P5 TO P2)

1 HEAT P6 TO 275°F ±25°F.

2. APPLY THE HEATED P6 TO ONE OF THE PARTS TO BE BONDED (P2 OR P5) AND IMMEDIATELY PLACE IT IN CONTACT WITH ITS MATING MEMBER.

3 HOLD IN PLACE UNTIL THE ADHESIVE IS COOL.

Figure 2 3.1.1.1-2. Collector Shroud

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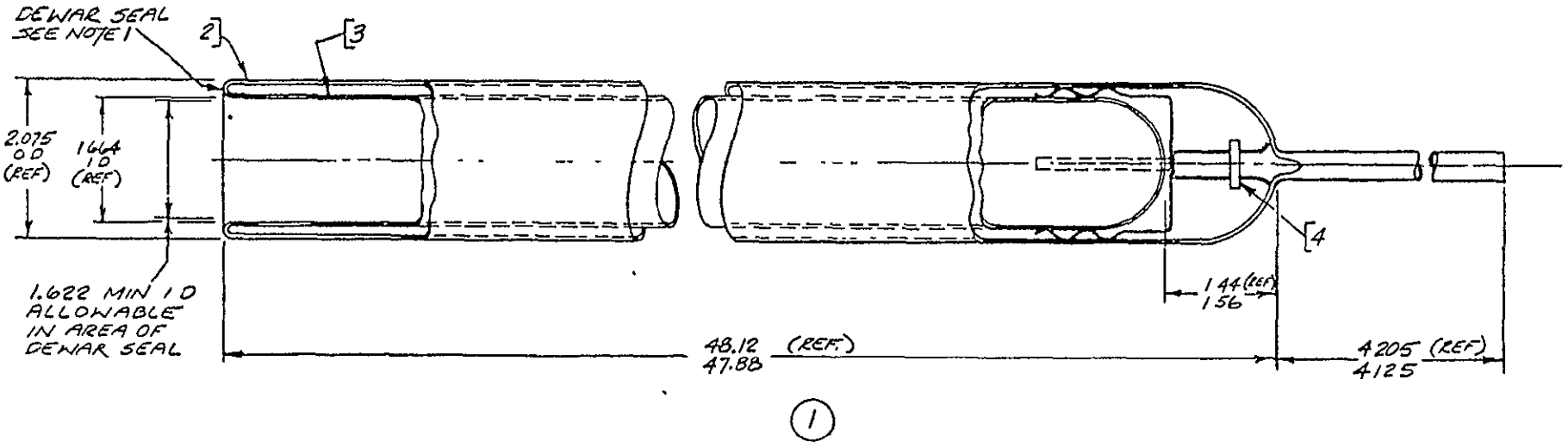
GROUP NO. QUANTITY										GI	DN	NAME	DESCRIPTION
										X	1	ASSEMBLY	
										1	2	OUTER TUBE	197B2381G1
										1	3	TUNGSTEN FIBER CONTROL	197B2411P1
										1	4	GETTER ASM	273A6023P1



NOTES:-

1 DEWAR SEAL SHALL HAVE SMOOTH SECTION TRANSITIONS. NO ABRUPT CHANGES IN THICKNESS OR CONTOUR IS PERMITTED. THICKNESS VARIATIONS SHALL NOT EXCEED ±25% OF THE STOCK DIMENSIONS.

Figure 2.3.1.1.1-3 Collector Shroud Subassembly

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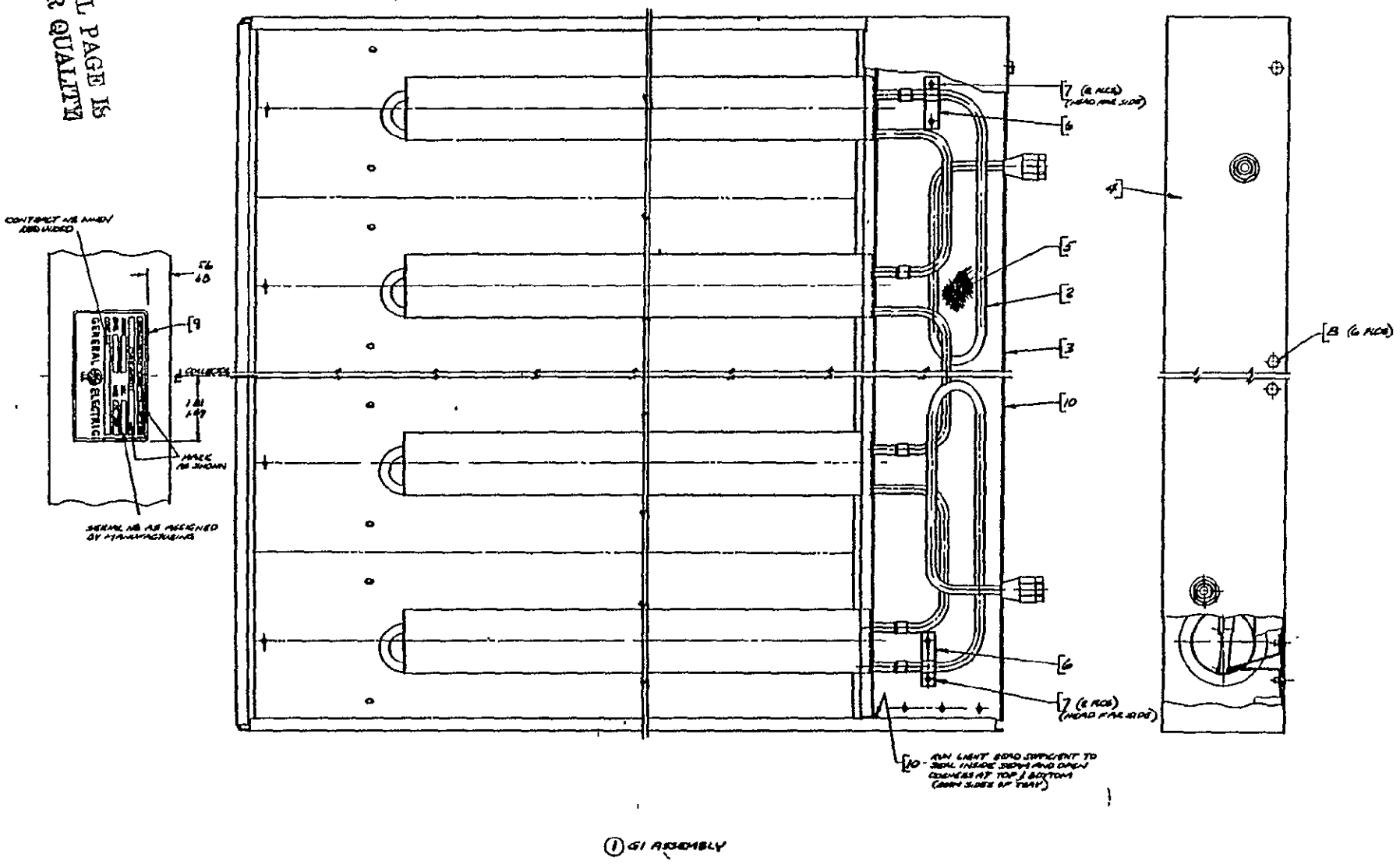


Figure 2.3.1.1.1-4 Collector Frame and Serpentine Assembly

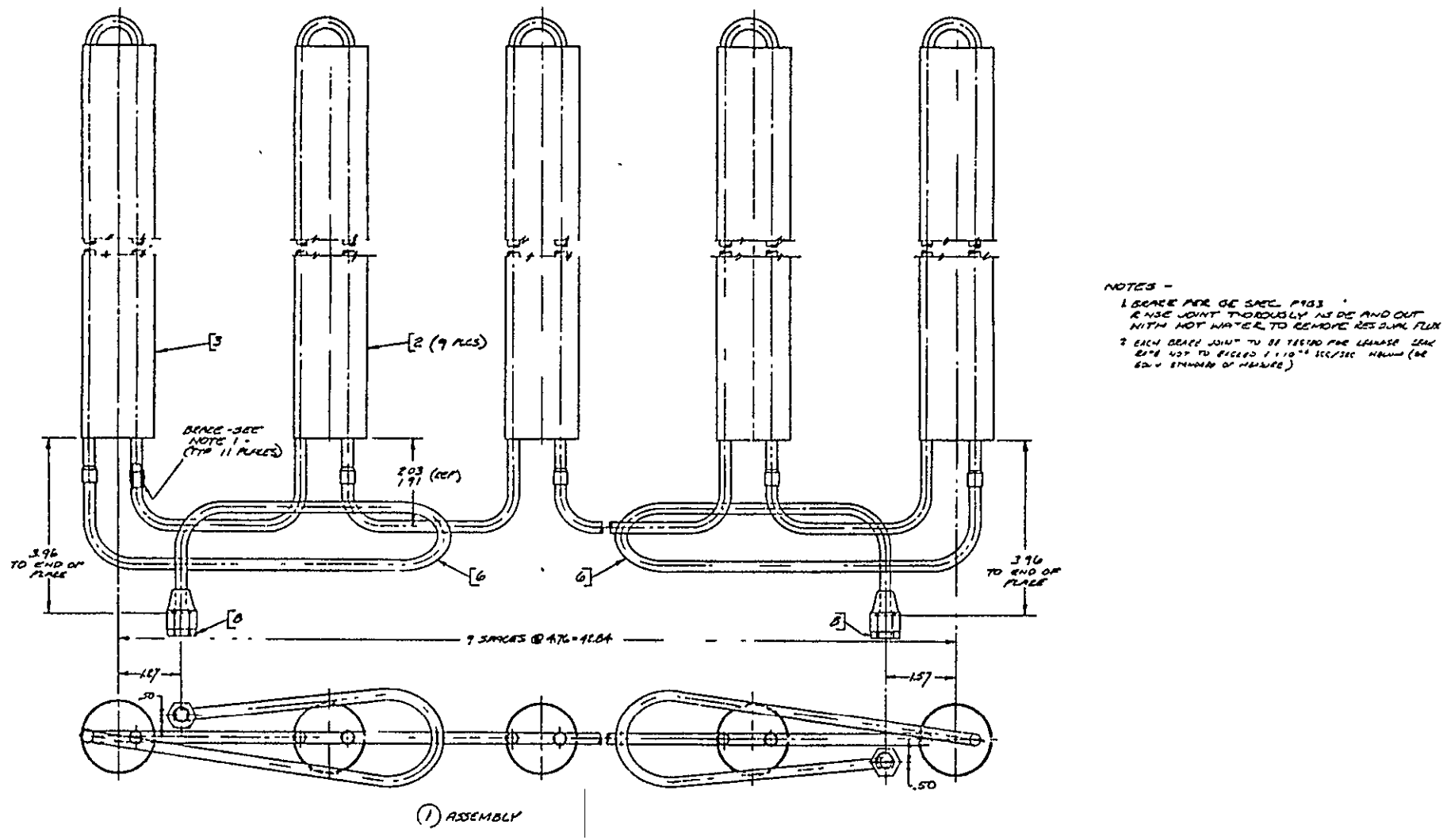


Figure 2.3.1.1.1-5 Serpentine Assembly

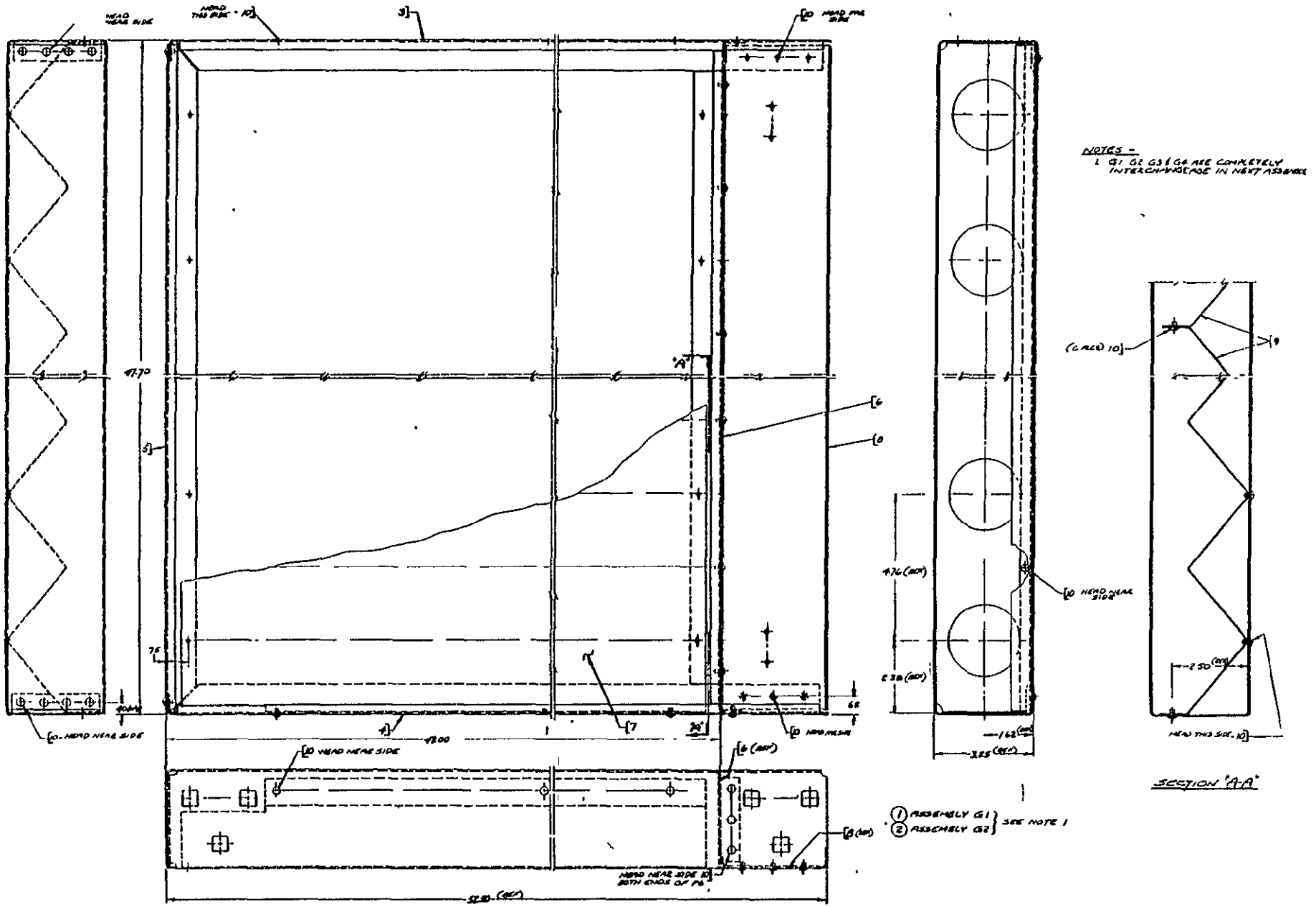
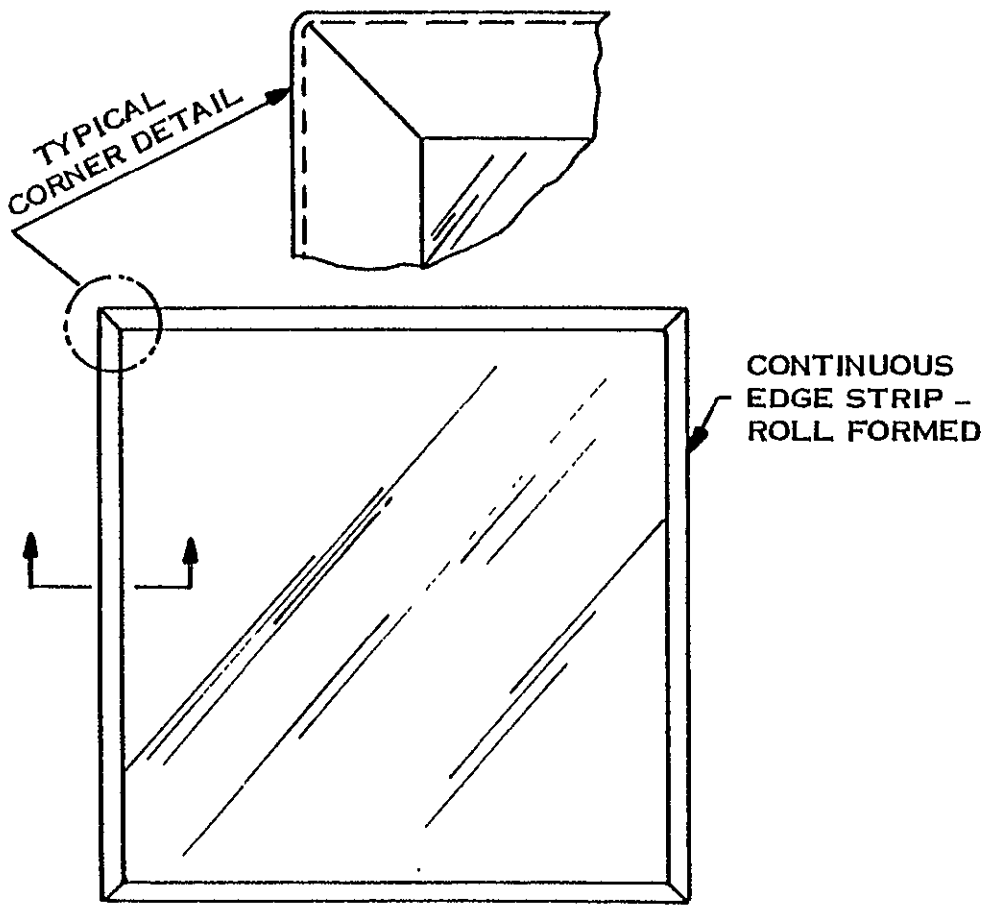


Figure 2.3.1.1.1-6. Frame and Reflector Assembly



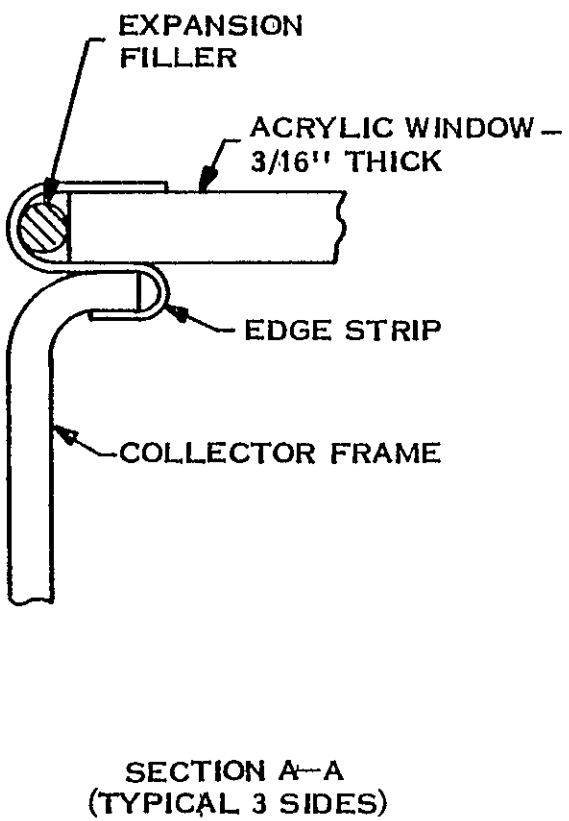


Figure 2.3.1.1.1-7. Protective Window Concept

Our secondary objectives were to demonstrate the relatively better performance we can expect from a tubular collector over a flat plate collector on a daily efficiency basis. We expected to see a relatively constant efficiency for the TC-100 up to temperatures of 300°F. We expected to see no effect of declination angle on efficiency and we expected reasonable performance on cloudy days (days of low insolation). All of our expectations were confirmed Charts of daily performance are offered as examples and are shown in Table 2.3.1.1.1-2 and Figures 2 3.1.1.1-8 through 2.3 1.1.1-13.

Four qualification units are being fabricated for a planned series of qualification tests. One of these units will be shipped to Desert Sunshine for performance testing. A two unit setup involving a simulated residential roof installation has been constructed at Valley Forge and two of the units will be installed on it for outdoor testing. Problems were encountered in the final assembly and checkout (shroud installation) of these items. Design modifications are being prepared to reduce interferences, facilitate assembly, and resolve other suspect problems that showed up in the hardware cycle.

Table 2.3.1.1.1-3 summarizes the successful solar collector loop verification tests. Two systems were utilized to verify performance and characterize loop components. The collector operational test facility, designated as "solar loop", was used during actual collector module operation. The "engineering loop" is a specially fabricated indoor facility with simulated collectors which was monitored extensively for performance verification.

The loop also performed as part of the working fluid stability studies The conclusions to date are:

- No gross decomposition of Prestone II indicated by any test performed, except in a closed system at 725°F.
- No attack on copper tubing at 250°F after 3000 hours
- No attack on 14 mil copper tubing at 290°F after 500 hours

  Brass fittings and fusion-brazed joints also satisfactory

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Table 2.3.1.1.1-2. TC-100 Verification Test Data

DATE	TIME	INCIDENT ANGLE	FLUID TEMP	AMBIENT AIR	INSOLATION	η TEST	η COMP	COMMENTS
12- 5-76	11:15 12:24 13:21	16 7 17	260 260 260	32 34 36	270 265 240	0.50 0.51 0.45	0.48 0.52 0.47	0° SOLAR DECLINATION
12- 9-76	11:13 11:58	25 22	145 145	30 30	255 270	0.50 0.53	0.53 0.57	23° SOLAR DECLINATION
12-10-76	12:36	24	190	48	259	0.49	0.52	23° SOLAR DECLINATION
12-14-76	12:11 12:00	23 22	230 230	31 31	260 260	0.50 0.50	0.52 0.54	23° SOLAR DECLINATION
12-22-76	11:41	23	205	27	250	0.48	0.52	23° SOLAR DECLINATION
1-20-77	12:09 12:24 11:47	1 3 6	220 220 220	31 31 30	285 285 285	0.52 0.51 0.50	0.52 0.51 0.51	0° DECLINATION
1-27-77	12:14 12:50	2 9	290 290	31 32	310 305	0.46 0.44	0.50 0.47	0° DECLINATION
1-20-77	8:58 10:23 10:56 13:29 14:22 15:43	45 25 18 19 31 50	205 210 210 210 210 200	27 30 32 31 32 30	150 245 265 270 220 130	0.28 0.41 0.45 0.45 0.37 0.27	0.34 0.43 0.46 0.47 0.39 0.33	0° DECLINATION

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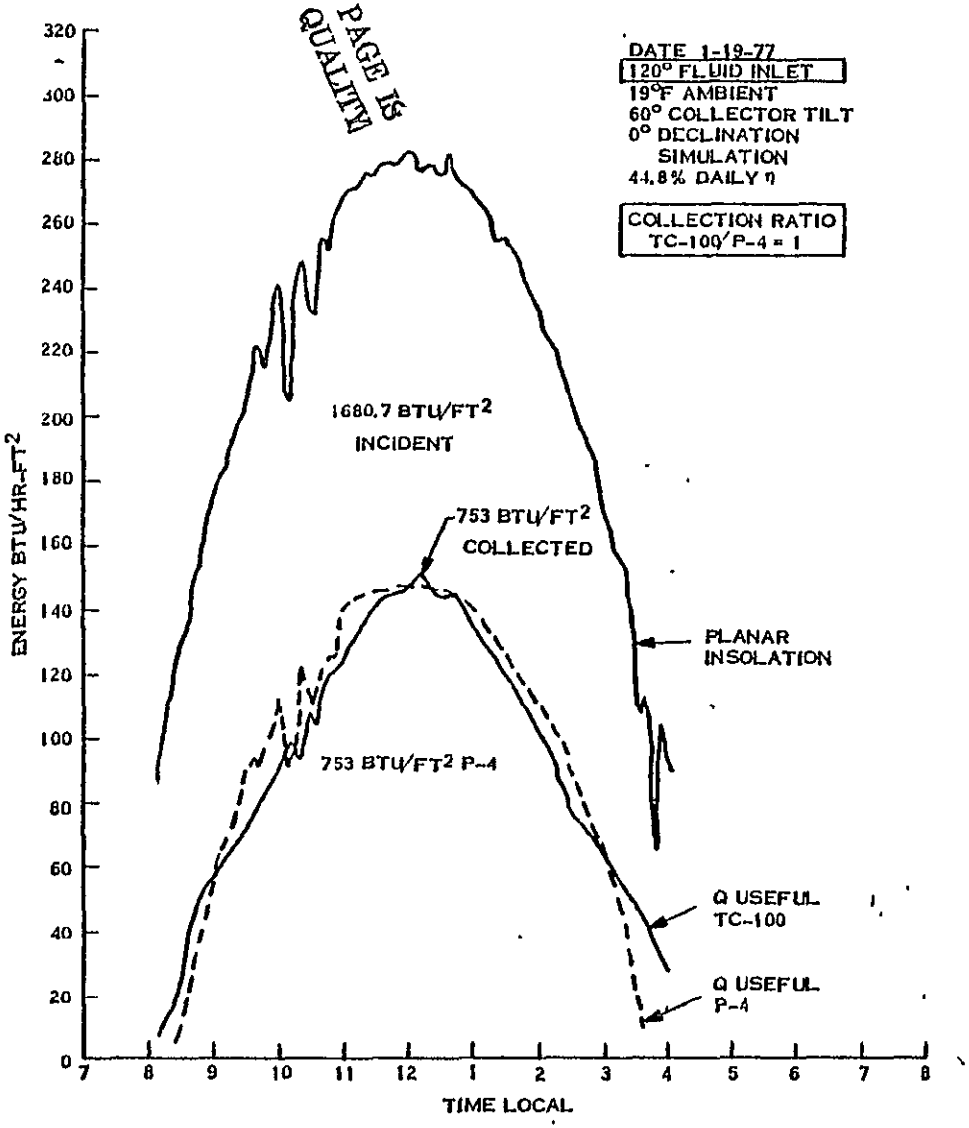

Figure 2.3.1.1.1-8. TC-100 Daily Performance (1/19/77)

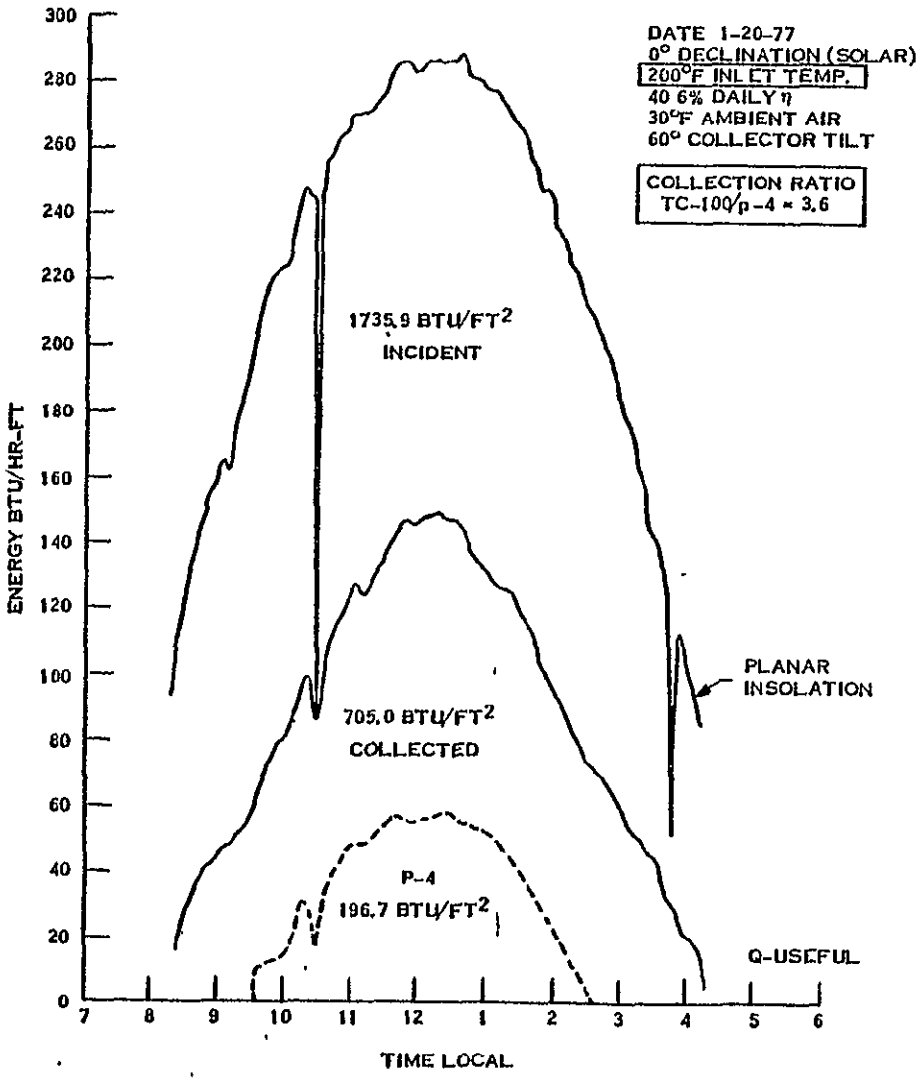

Figure 2.3.1.1.1-9. TC-100 Daily Performance (1/20/77)

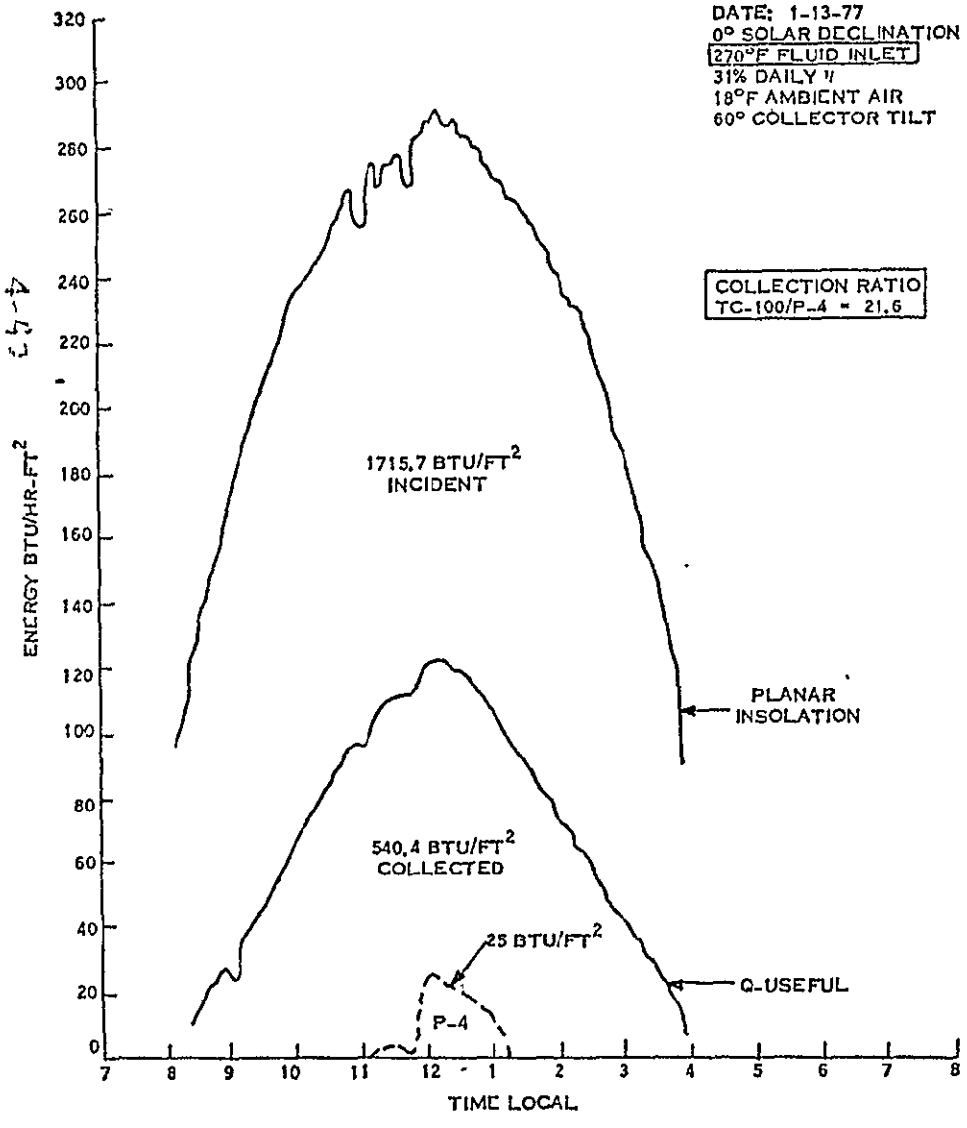

Figure 2.3.1.1.1-10. TC-100 Daily Performance (1/13/77)

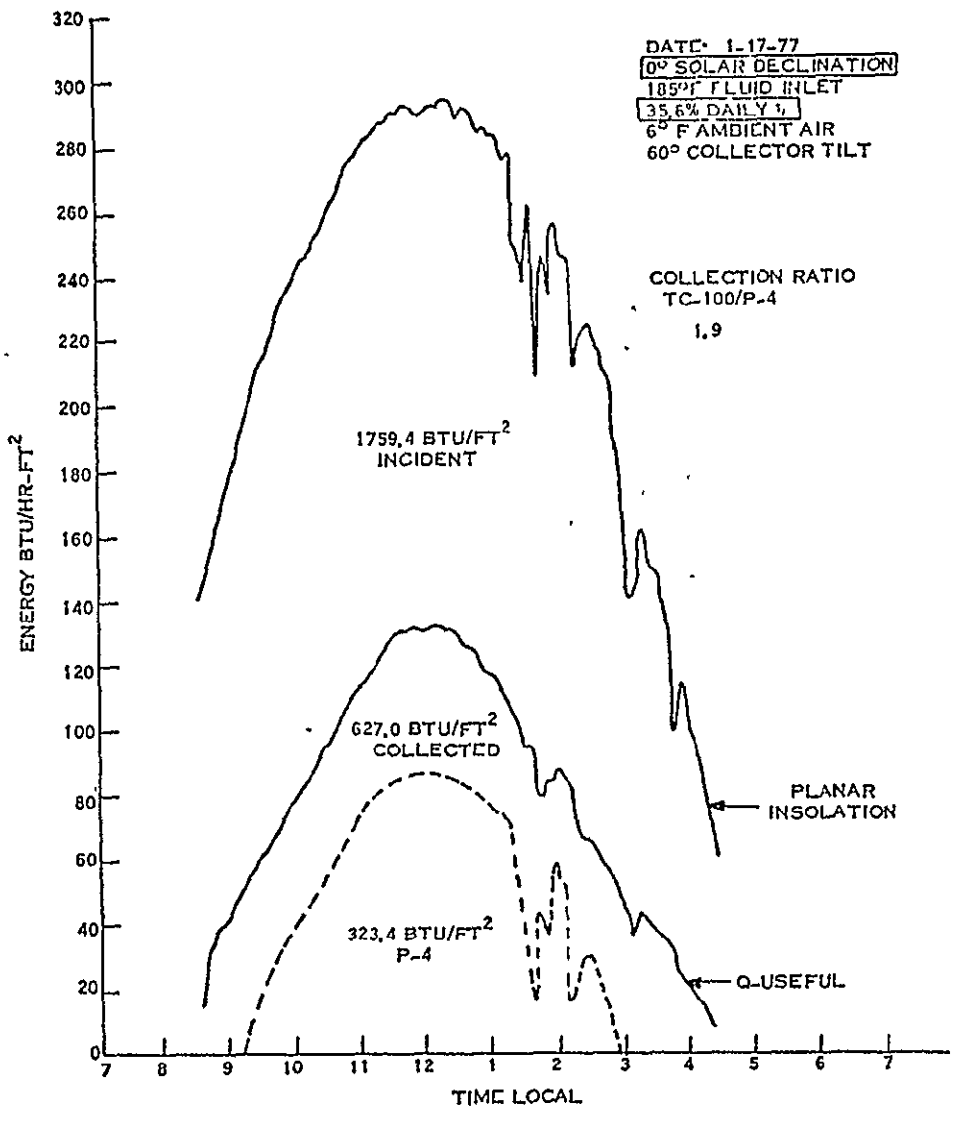

Figure 2.3.1.1.1-11. TC-100 Daily Performance (1/17/77)

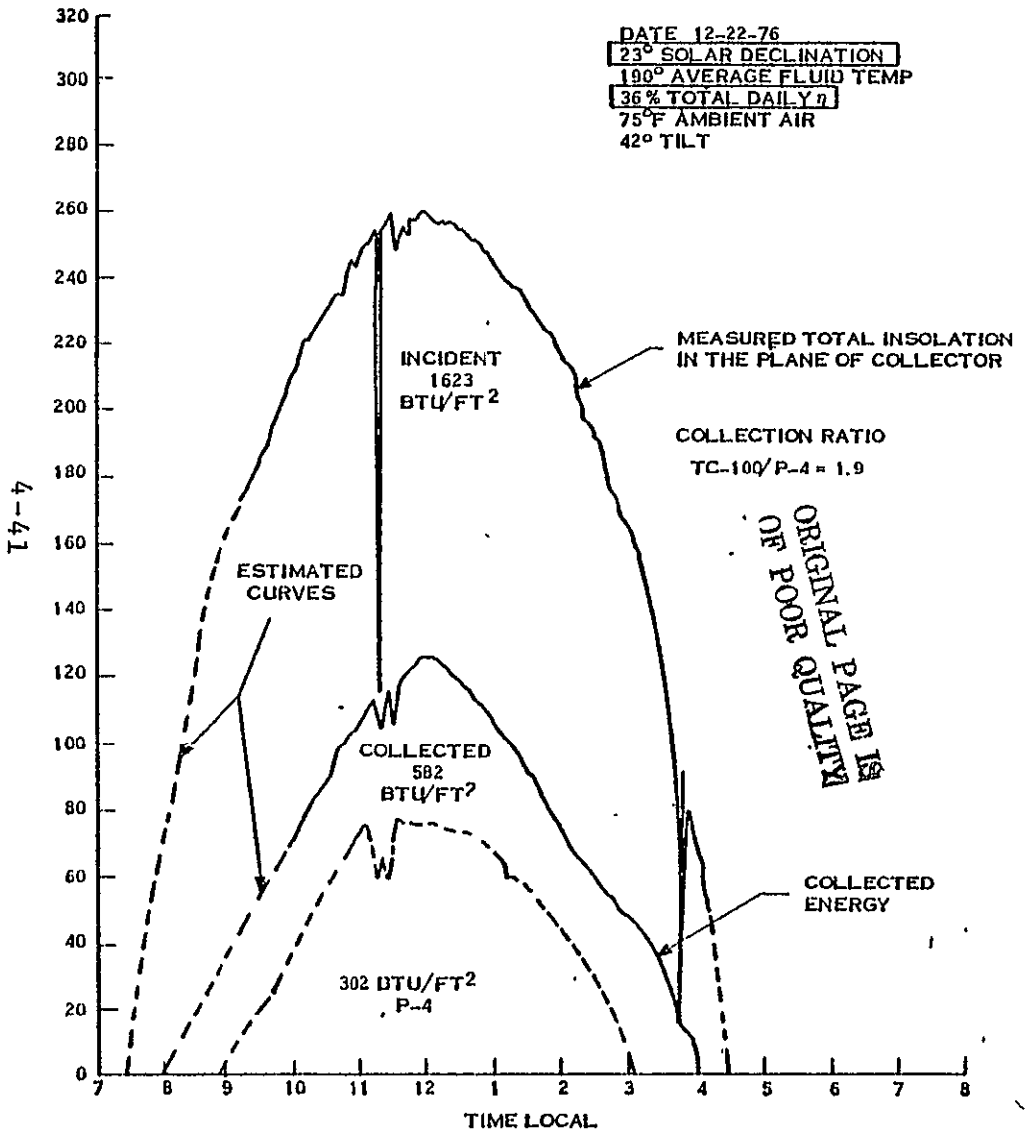

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Figure 2.3.1.1.1-12. TC-100 Daily Performance (12/22/76)

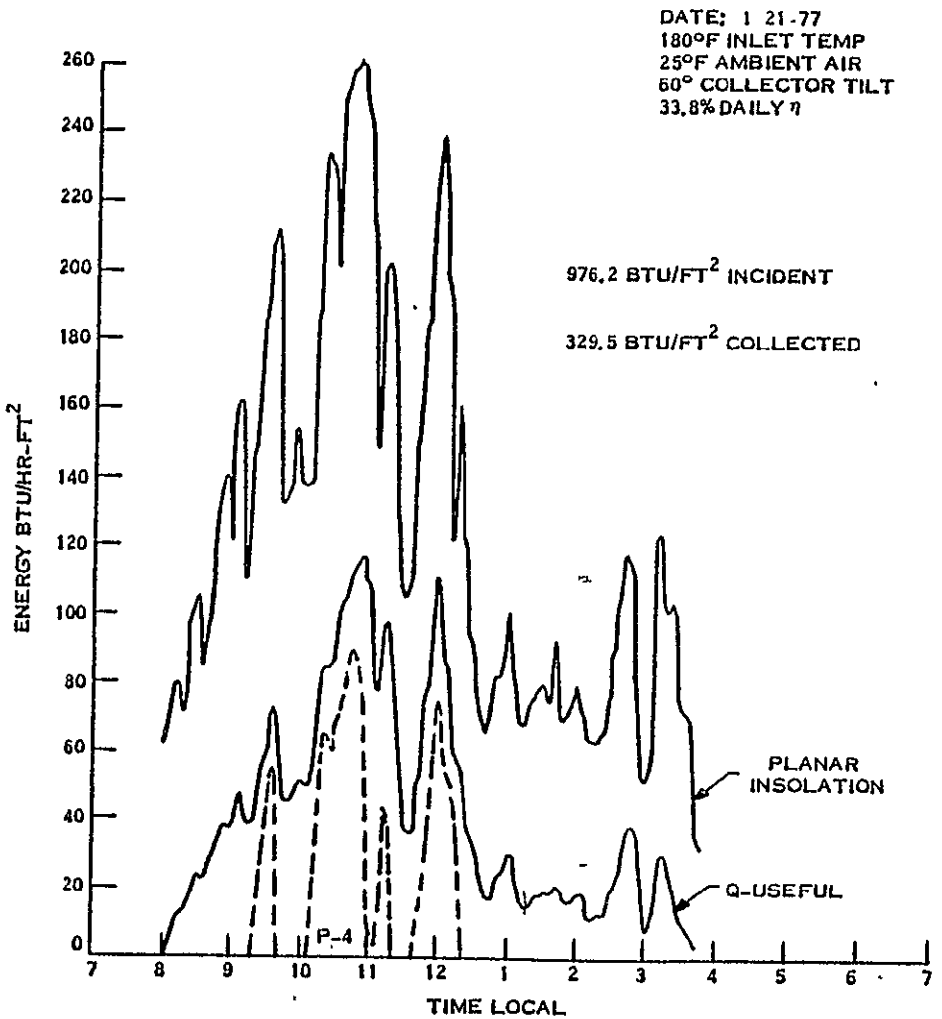

Figure 2 3.1.1.1-13. TC-100 Daily Performance (1/21/77)

Table 2.3 1.1.1-3 Collector Loop Verification Test Summary

ENGR LOOP	SOLAR LOOP	TEST	CONCERN	RESULTS
X	X	START UP	SERPENTINE FILL	TOTAL FILL EVERY TIME
X		AIR SEPARATION	PUMP AIR ENTRAPMENT	COMPLETE SEPARATION OBTAINED AT AIR SEPARATOR
X	X	SERPENTINE BLOCKAGE	ADDITIVE RESIDUES BLOCK PASSAGEWAYS	SERPENTINE ALWAYS CLEAR
X	X	STAGNATION START UP	STEAM HAMMER	o DEAD HEADS PUMP o MINOR PRESSURE FLUCTUATIONS o SELF REGULATING
X	X	BLOWDOWN VAPOR CONDENSATION	RISE IN PRESSURE DUE TO INSUFFICIENT VAPOR CONDENSATION	SLOW BUILD UP TO DESIGN PRESSURE
X		HEAT REJECTION	SUFFICIENT HEAT REJECTION RATE	REJECTION CAPABILITY GREATER THAN INPUT RATE

2.3.1.1.2 Collector Primary Loop

It was imperative to establish a collector loop configuration that is not only an efficient energy transport system, but entirely compatible and non-restrictive with the collector itself To this end, the primary loop has been developed

The system is a closed loop using a water-ethylene glycol mixture in a 35-50% by volume ratio as the working fluid to prevent freeze-up in colder climates. Standard, commercially available components have been selected and characterized to perform the various hydronic functions. Sizing-up of the components for larger collector systems permits the utilization of one basic loop configuration. Figures 2.3.1.1.2-1 and 2.3.1.1.2-2 shows the minor differences between the residential system of 40 collectors or less, and the commercial and industrial system of 40 collectors or more. Aside from the component size and capacities, the only difference between the system configuration is the heat dump/vapor

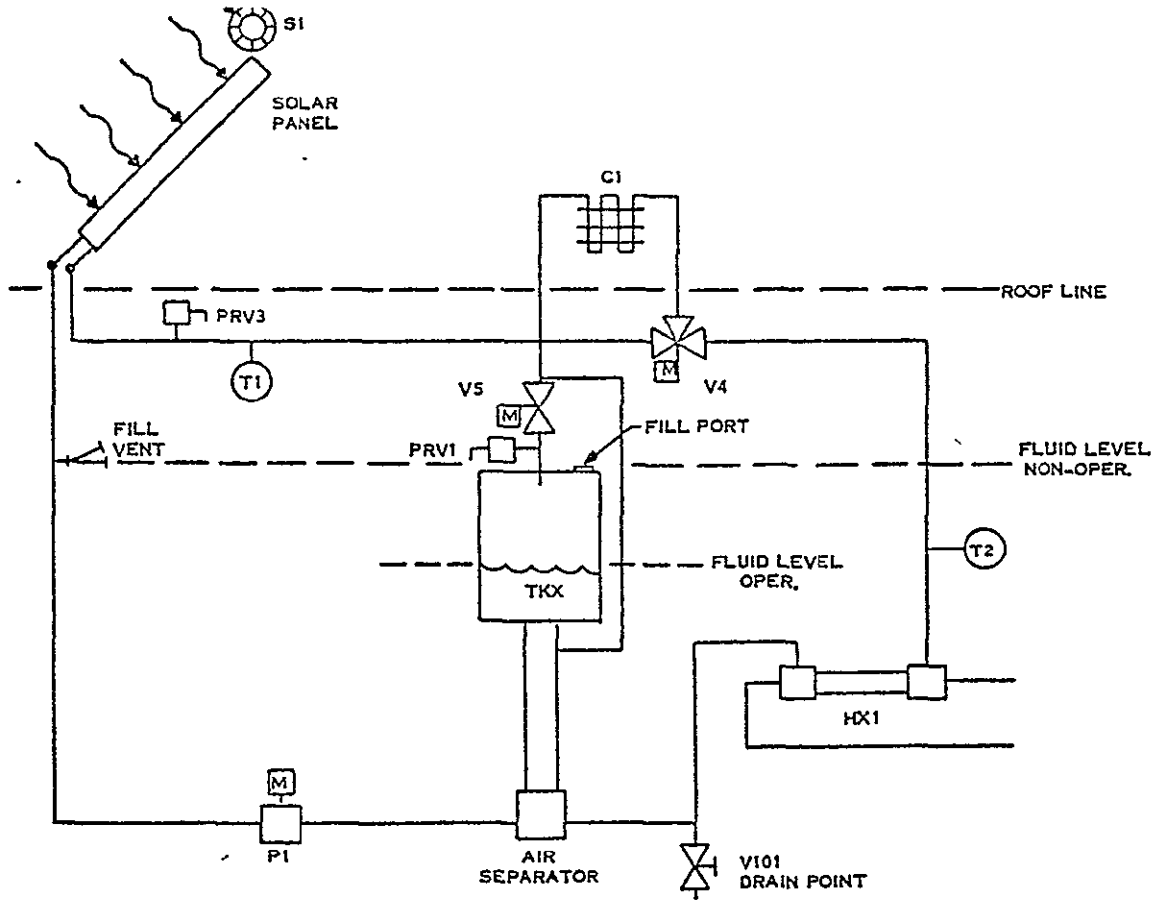

Figure 2.3.1.1.2-1. Collector Loop Residential Systems (40 Collector Maximum)

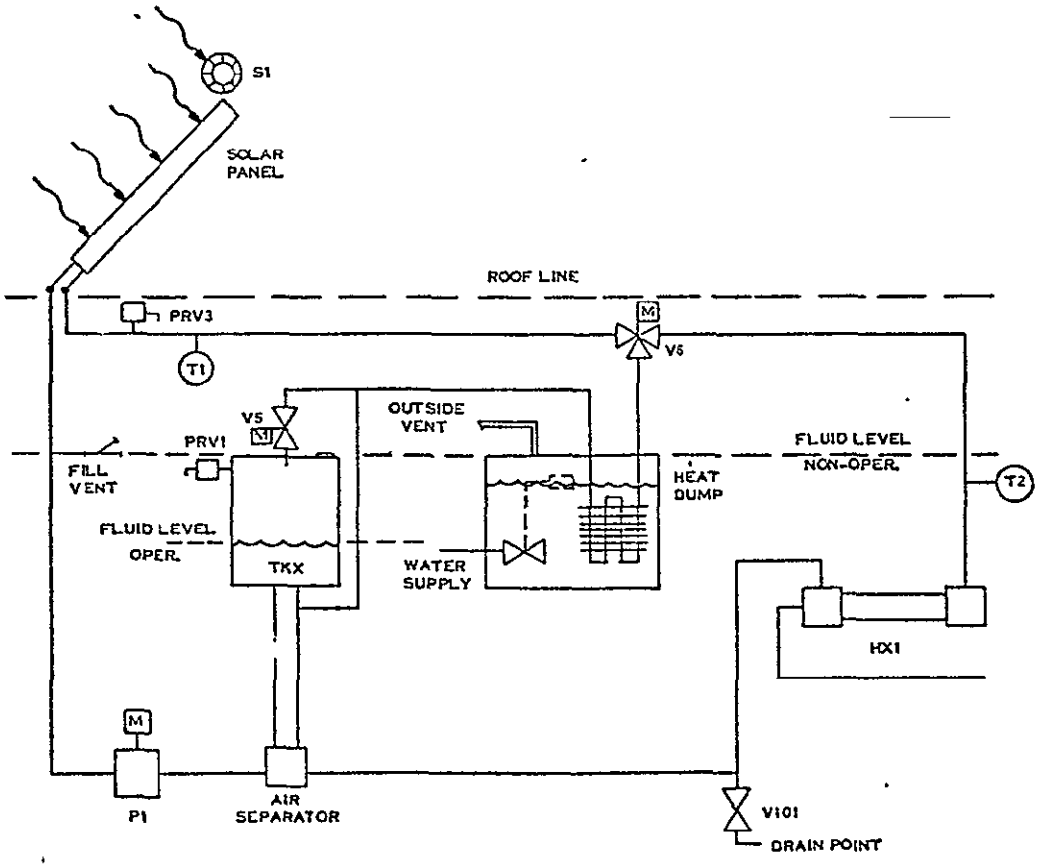

Figure 2.3.1.1.2-2. Collector Loop Commercial and Industrial (40 Collectors Or More)

condenser (CI) where the larger systems warrant a more efficient unit. The control logic and operational modes are identical. Figures 2.3.1.1.2-3, 2.3.1.1.2-4 and 2.3.1.1.2-5 define the operational modes where the arrows indicate fluid (liquid/vapor flow. Table 2.3.1.1.2-1 summarizes the loop components and their basic functions.

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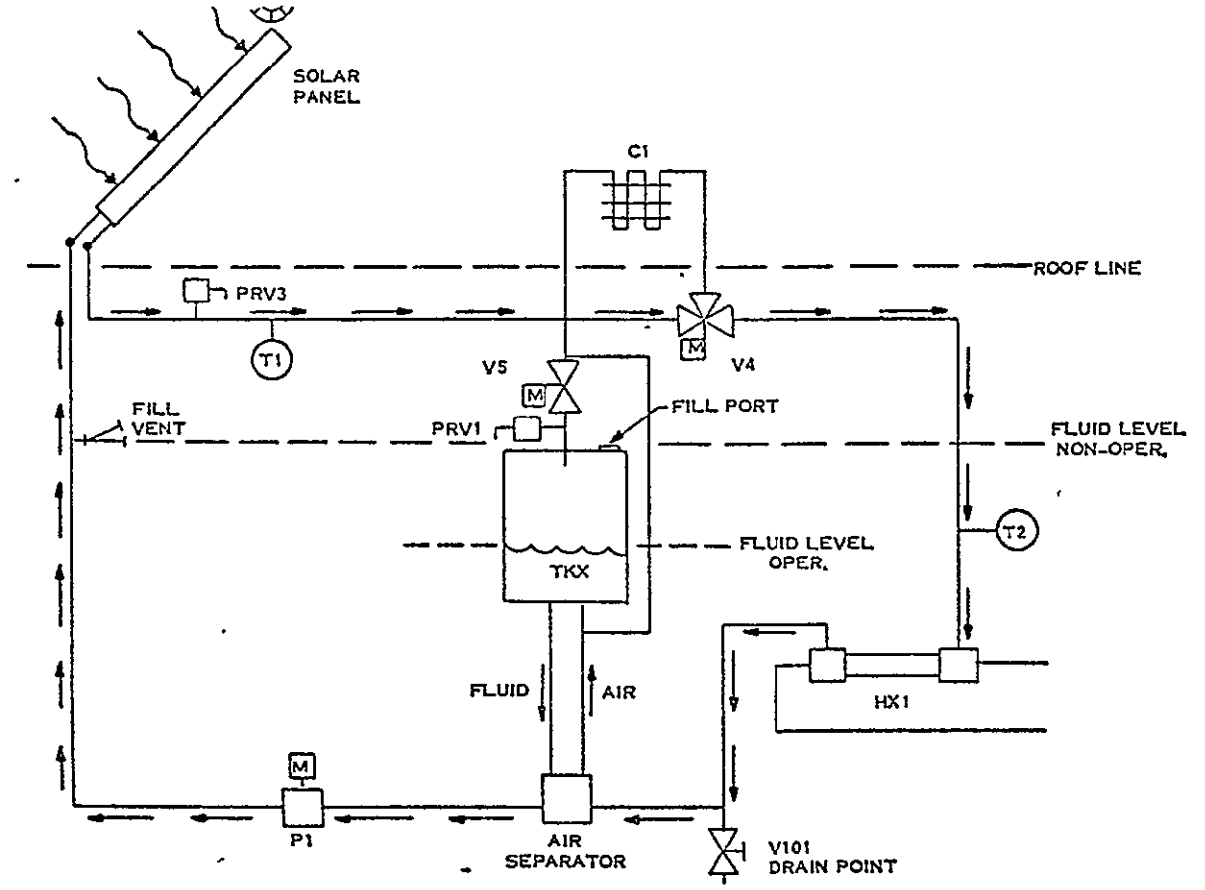

Figure 2.3.1.1.2-3. Collector Loop Energy Collection

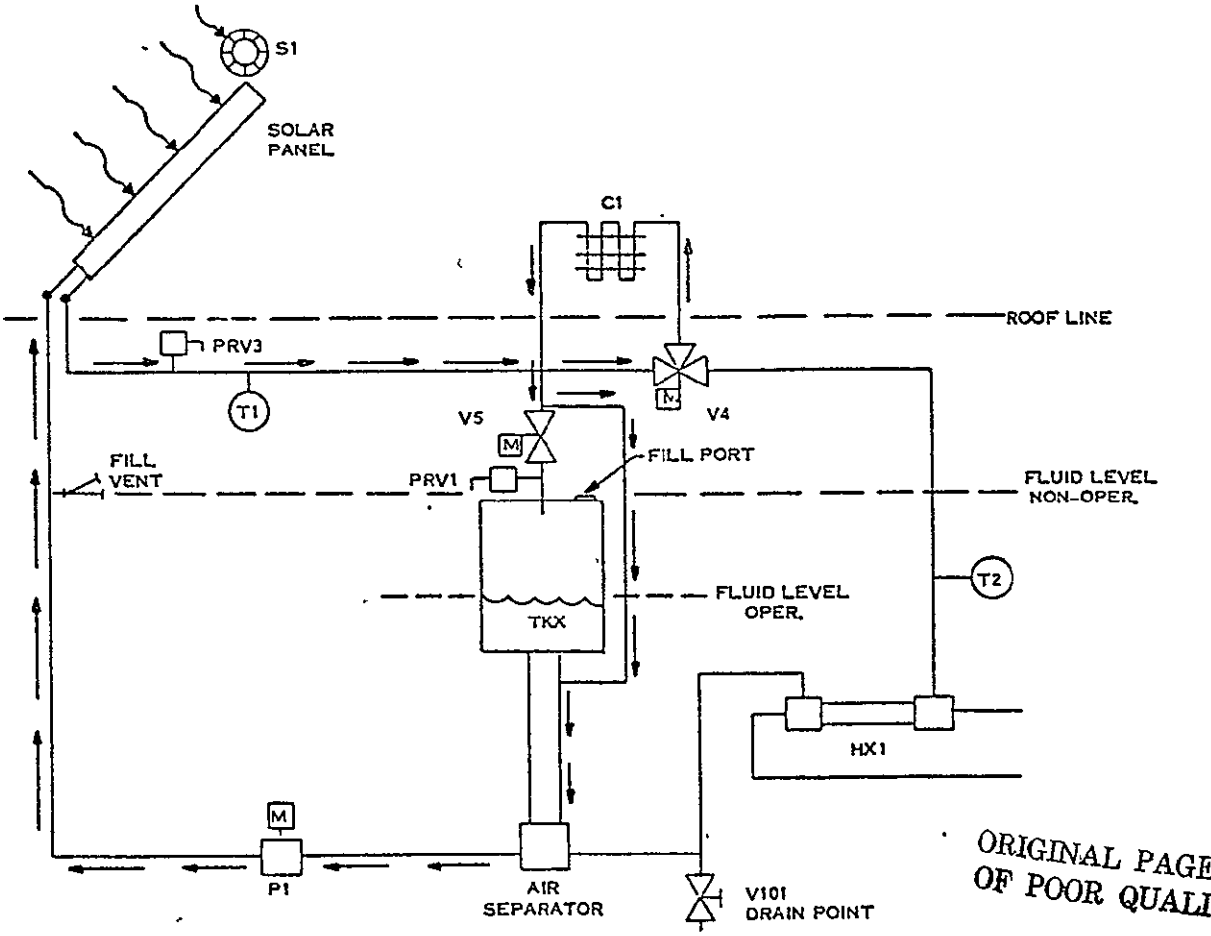

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Figure 2.3.1.1.2-4. Collector Loop Heat Rejection

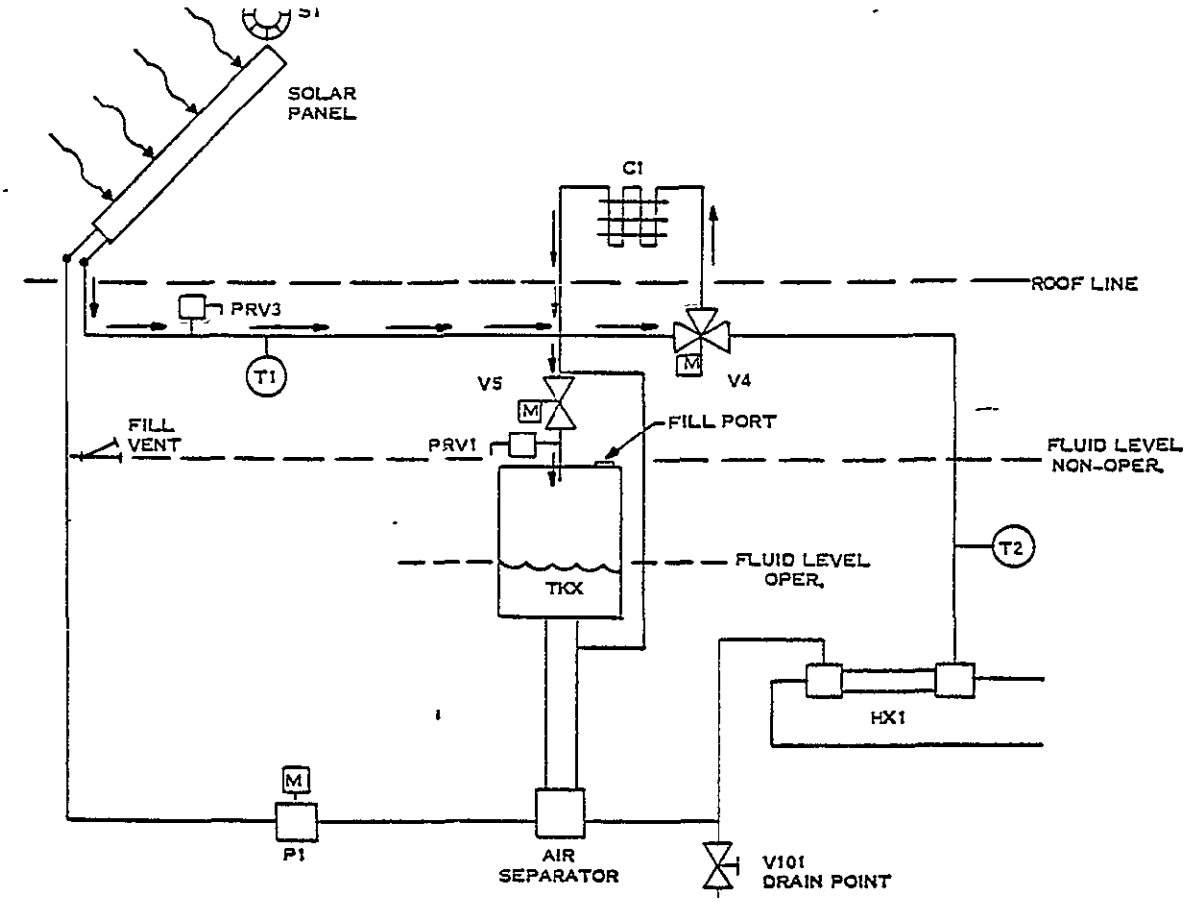

Figure 2.3.1.1.2-5. Collector Loop Power Loss

Table 2.3.1.1.2-1. Primary Loop Components

COMPONENT	FUNCTION
TC-100 Collector Modules	Collect solar energy efficiently over a wide range of fluid temperatures and solar insolation values.
S1-Solar Sensor	Measures the solar insolation and indicates start-up and shut-down modes for the control system.
PRV1 & PRV3 - Pressure Relief Valve	Prevents over-pressurization of the collector system due to elevated temperature conditions.
V4 - Diverting Valve	Diverts the working fluid to the heat dump mode when the thermal energy is not required. This mode prevents excessive over-temperature situations. Also, this valve permits vapor to reach the condenser in the power loss mode.
T1 & T2 Temperature Sensors	Fluid temperature indicators for the control system.
HX1 - Heat Exchanger	Transfer the thermal energy from the closed primary loop
V101 - Drain Valve	Maintenance valve for draining the power loop.
Air Separator Valve	Separates air from the working fluid especially during start-up where large values of displaced air are forced through the lines.
P1 - Pump	Circulation pump for the working fluid.
Fill/Vent Valve	Maintenance valve for filling and venting the system.
TKX Storage Tank	Valving require to store working fluid in the non-operating mode. Also provides expansion capability.

Table 2.3.1.1.2-1. Primary Loop Components (Cont'd.)

COMPONENT	FUNCTION
VS - Vent Valve	Permits entrapment of air in the storage tank when closed. When opened during power-off conditions permits air to return to the collector portion of the system.
C1 - Heat dump/Vapor Condenser	This component is a conventional fin and tube liquid-to-air heat exchanger for the residential systems to reject heat in the heat dump mode and condense vapor in the power-off mode. Larger systems perform the same function but utilizes a more efficient heat exchanger than the fluid-to-air concept.

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2.3.1.2 Energy Storage

Specification 261A2870, "Tank Assembly, Thermal Energy Storage and Expansion," was issued. This specification covers all components associated with the thermal energy storage function, including the TES tank itself, the tank insulation, the domestic hot water heat exchanger, the expansion tank, relief valve, and other air and fluid maintenance components.

In addition, specification 261A1867, "Tank Assembly, Energy Transfer, Storage and Expansion," was issued. This specification is directed toward a two loop solar system, in that the collector loop heat exchanger was included as part of the overall energy storage tank assembly.

Requests for proposal for these two tank assemblies, covering the full range of system building block sizes, were sent to more than tank manufacturers, throughout the country.

One manufacturer in particular, Wood Industrial Products Company, has provided definitive cost tradeoff data, which has indicated that the two loop system, with an in-tank collector loop exchanger, is not a cost effective approach, at this time. There are two main factors that lead to this conclusion. The in-tank natural convection type of heat exchanger is significantly less effective than a shell and tube heat exchanger, which in turn requires substantially more surface area to achieve an equivalent energy transfer; this makes the in-tank exchanger costs five to ten times more than an equivalent shell and tube unit. In addition, the tank modification required to install the in-tank exchanger becomes a significant portion of overall tank costs (up to 50% for residential sizes). The overall savings for a two loop system (i.e. the

elimination of the storage loop pump and reduced piping requirements) are small in comparison to the aforementioned cost growth factors.

Therefore, the basic three loop system has been selected for the initial operational test sites.

2.3.1.3 Space Heating and Cooling

Specification 261A2861, "Hydronic Coils" and Specification 261A2859, "Air Handlers" were ready for issue, but were recalled based on an update of the system building block requirements.

2.3.1.4 Auxilliary Energy Systems

Specification 261A2884, "Auxilliary Energy, Boiler," was issued and vendors have been contacted. Specification 261A2858, "Auxilliary Energy, Forced Air Furnace," is 95% complete.

2.3.1.5 Hot Water Subsystem

Specification 261A2879, "Domestic Hot Water Tank," was issued and vendors identified and contacted.

2.3.1.6 Energy Transport Subsystem

All pump and valve specifications were issued and vendor comments and cost data were accumulated.

As a result of the overall system cost evaluations that were performed using the acquired vendor cost data, as well as to assure the technical success of the various installations, a pre-packaged "Energy Management Module" is being developed, which includes various components of the three loops in a compact self-contained unit. For residential application, the module will be contained in a visually appealing cabinet; for the multi-

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family and commercial applications, the module will be mounted on a palletized truss type structure. Included in the Energy Management Module will be the following components.

1. collector loop storage/expansion tank
2. pressure relief valve
3. fill valve
4. drain valve
5. collector loop pump
6. collector loop heat exchanger
7. storage loop pump
8. air separator
9. distribution loop pump
10. two position soleroid valve

2.3.1.7 Combined Function Components

No significant activity during the reporting period.

2.3.1.8 Controls Subsystem (WBS 1.2.2.1.7)

2.3.1.8.1 System Design

The system design has changed during the last quarter with respect to the controls philosophy for collection and storage of energy. Earlier system design discussions described a development item termed a Solar Integrator which measured average insolation rate and provided an output signal to operate the collector loop pump. System studies have indicated that proper selection of the solar integrator set point allows this signal to also operate the storage loop pump.

Figure 2.3.1.8 shows the present collection and storage loops for Heating Single Family. The system design for Heating Multi-Family and Heating Commercial is identical to the Single Family except for component sizes and the types of passive heat rejection system (C-1 in Figure 2.3.1.8). The previous design used the Solar Integrator (S-1) to operate pump P-1. After a time delay, the Solar Integrator energized a second output, powering valve V4 to "A" flow (spring-return, "B" flow de-energized) and powering valve V5 closed (solenoid, normally open). Analog temperature sensors, T2 and T3, were compared in the electronic controls package to determine the turn on point (T2 - T3 $20^{o}F$) for pump P-2.

The new system design operates pump P-1 and valves V4 and V5 in the same manner; however, pump P-2 is also energized on the second Solar Integrator output. System studies have shown that proper selection and operation of the Solar Integrator set point (insolation rate) gives the control system a true indication of available energy.

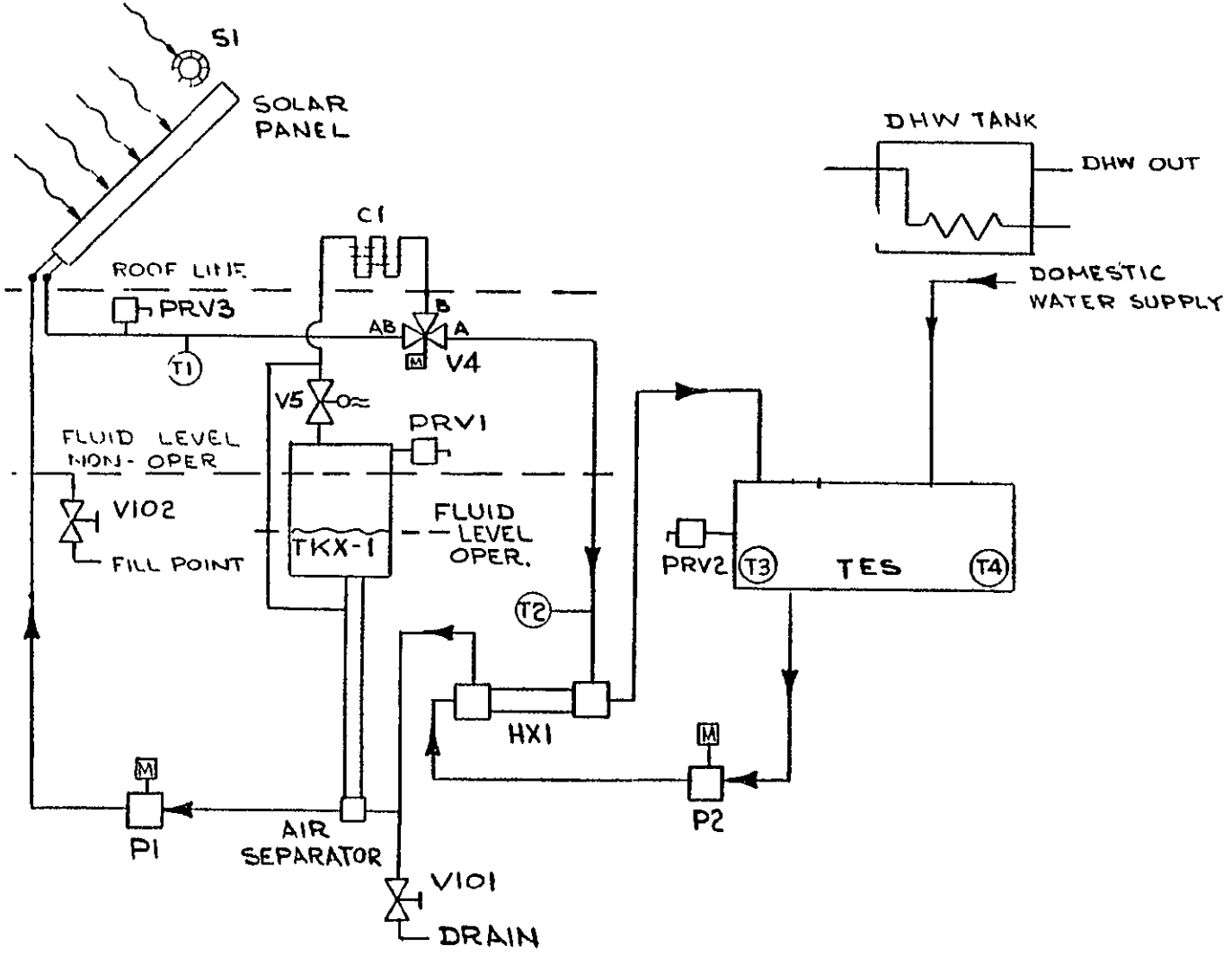

Figure 2.3.1.8-1. Heating System Collection and Storage Loop

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Given a well-insulated system, collector fluid temperature will quickly rise to the point at which collected solar energy is delivered to thermal storage with little storage energy loss during the start transient.

This removes the need for continuous analog temperature sensors and electronics. Sensor T2 has been removed from the system and sensor T3, which was an analog sensor used for both the storage differential and as a space heating set point, is replaced by a single set point thermal switch. The resulting simplified logic requires only three relays replacing an electronic circuit board and six triacs (power semi-conductors).

The distribution loops for Heating Single Family, Multi-Family and Commercial have been described in the first and second Quarterly Report, and have not been changed.

2.3.1.8.2 Component Development

2.3.1.8.2.1 Sensors - Sensor development has continued in three areas in this period; analog temperature sensors, thermal switches and solar integrator.

The nickel wire RTDs are the analog temperature elements. Although this sensor has been deleted in the Heating Systems, the sensor will be evaluated for Heating and Cooling and Solar Rankine Controls.

The thermal switch development has continued in the form of vendor contacts. Several companies have expressed interest in supplying the packaged switch. System testing will evaluate the use of surface-mounted thermal switches instead of the current immersion-type design.

Samples of both types will be evaluated on the system test.

The Solar Integrator, as described in the second Quarterly Report, is an electronic logic package which uses a silicon photodiode and digital logic to initiate solar energy collection. A new function, a delayed second output, has been added to the design.

An in-house designed printed circuit board has been fabricated and tested with all of the Solar Integrator function. A new modification, relay-isolated 24 VAC outputs, is under fabrication and will be included in the qualification testing.

2.3.1.8.2.2 System Controls Package - The latest system design removes the need for a printed circuit board and power triacs. As a result, two new development units consisting of three relays, three terminal strips and a 24 volt transformer have been packaged and are currently on test. One unit will be used to control the system test bed. Due to the simplicity of the new package, the design will be qualified by analysis.

2.3.1.9 Electrical Subsystem - The Heating Control/Electrical Subsystem Diagrams 132D6021 have been initiated. This drawing number contains three schematics and six tables. This amount of detail is needed to define the electrical components and interconnections for the fifteen Heating System building blocks. Figures 2.3.1.9-1 thru 2.3.1.9-3 are the preliminary schematics. The drawing in total will be available at PDR.

Fi gure 2.3.1.9-4 is a sketch of the Fort Meade Energy Management Module with its electrical interface defined.

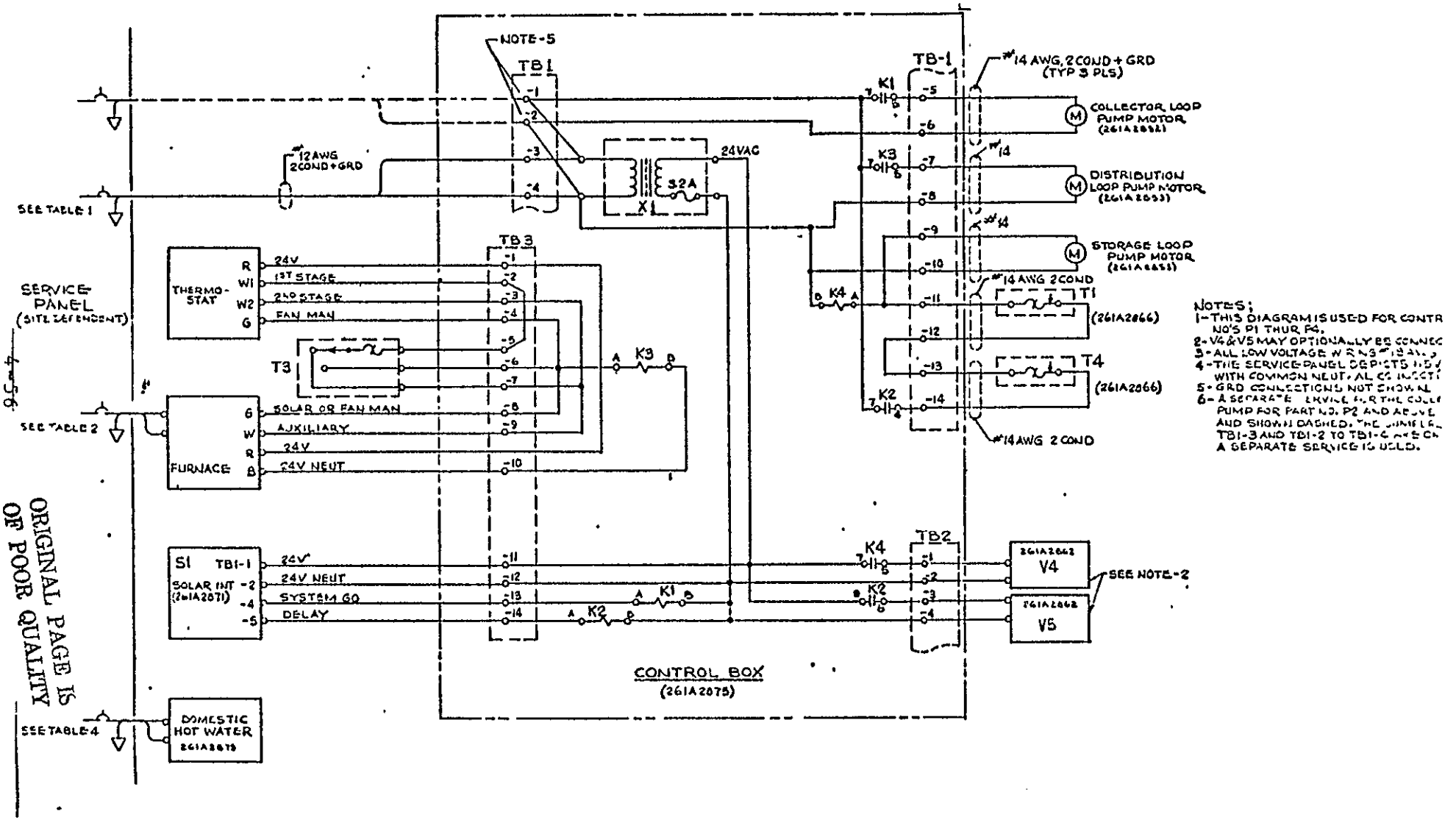

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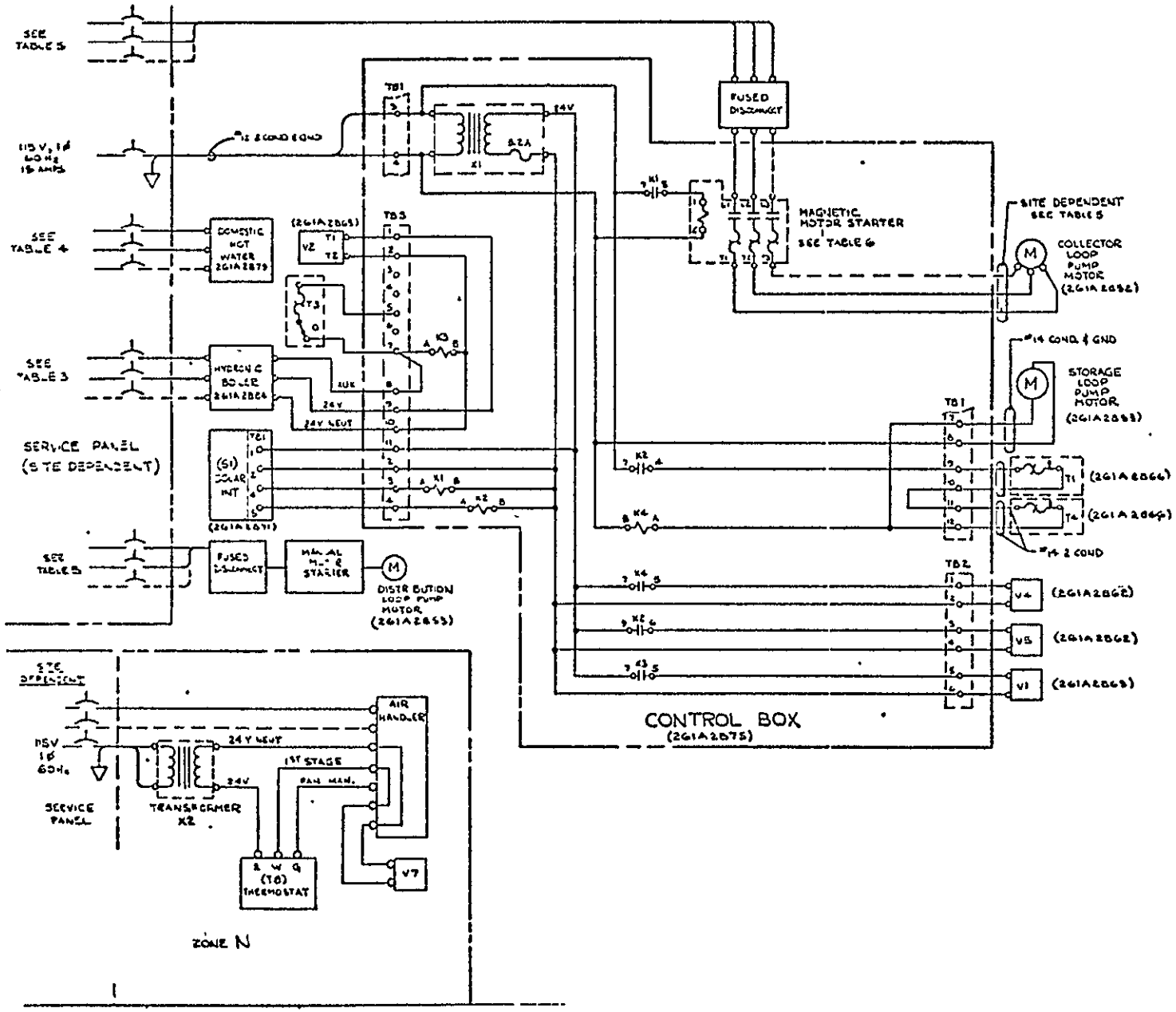
Figure 2.3.1.9-1. Heating Control/Electrical Schematic



NOTES:

1. THIS DIAGRAM IS USED FOR CONTROL BOX P NO'S P5 THRU 'TSD'
2. ALL LOW VOLTAGE WIRING #18 AWG U N
3. V1, V4, V5 MAY OPTIONALLY BE CONNECTED TO
4. GND CONNECTIONS NOT SHOWN
5. DASHED (- -) LINES SHOW OPTIONAL PHASE

Figure 2.3.1.9-2. Heating Control/Electrical Schematic

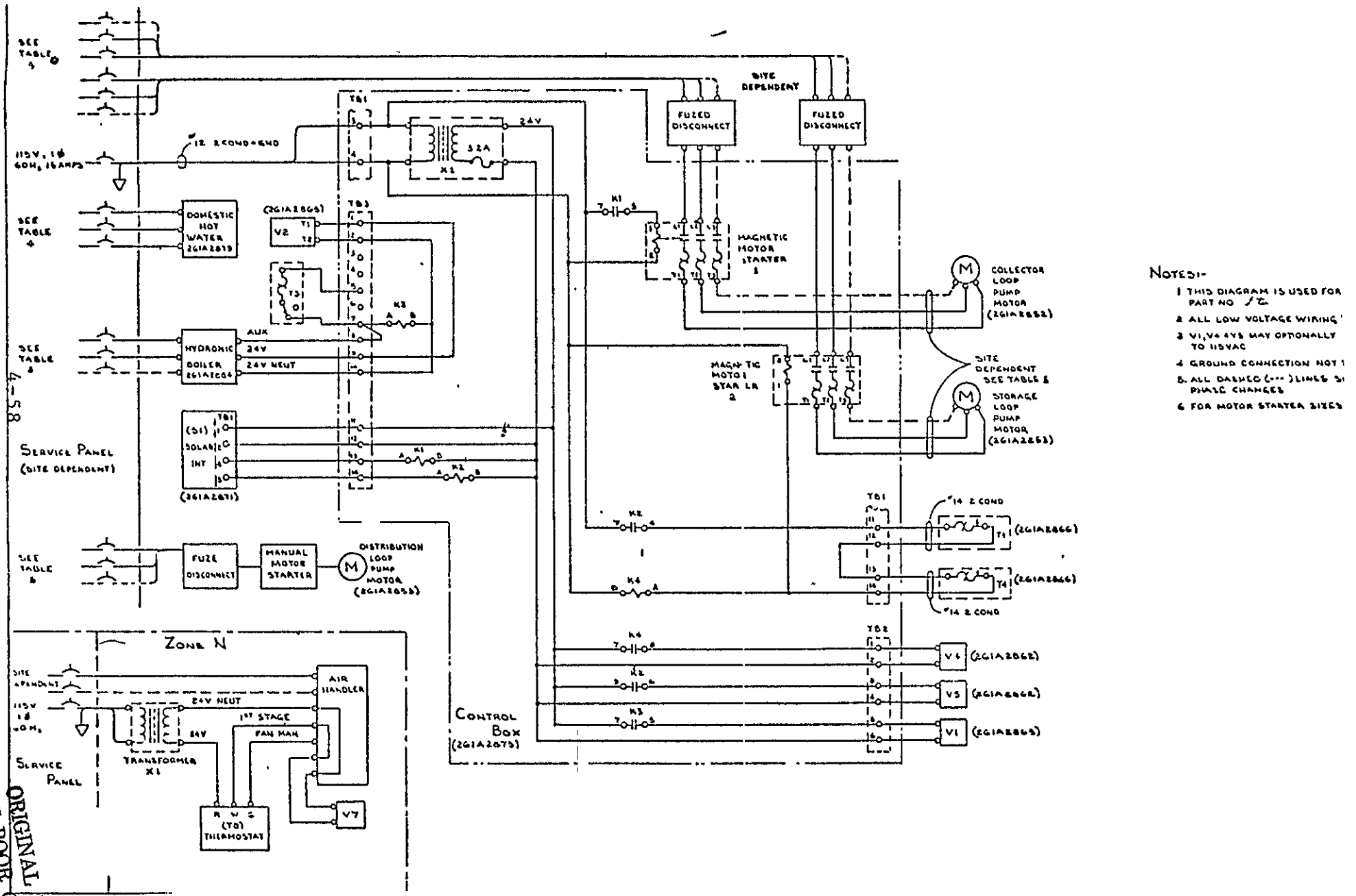


Figure 2.3.1.9-3. Heating Control/Electrical Schematic

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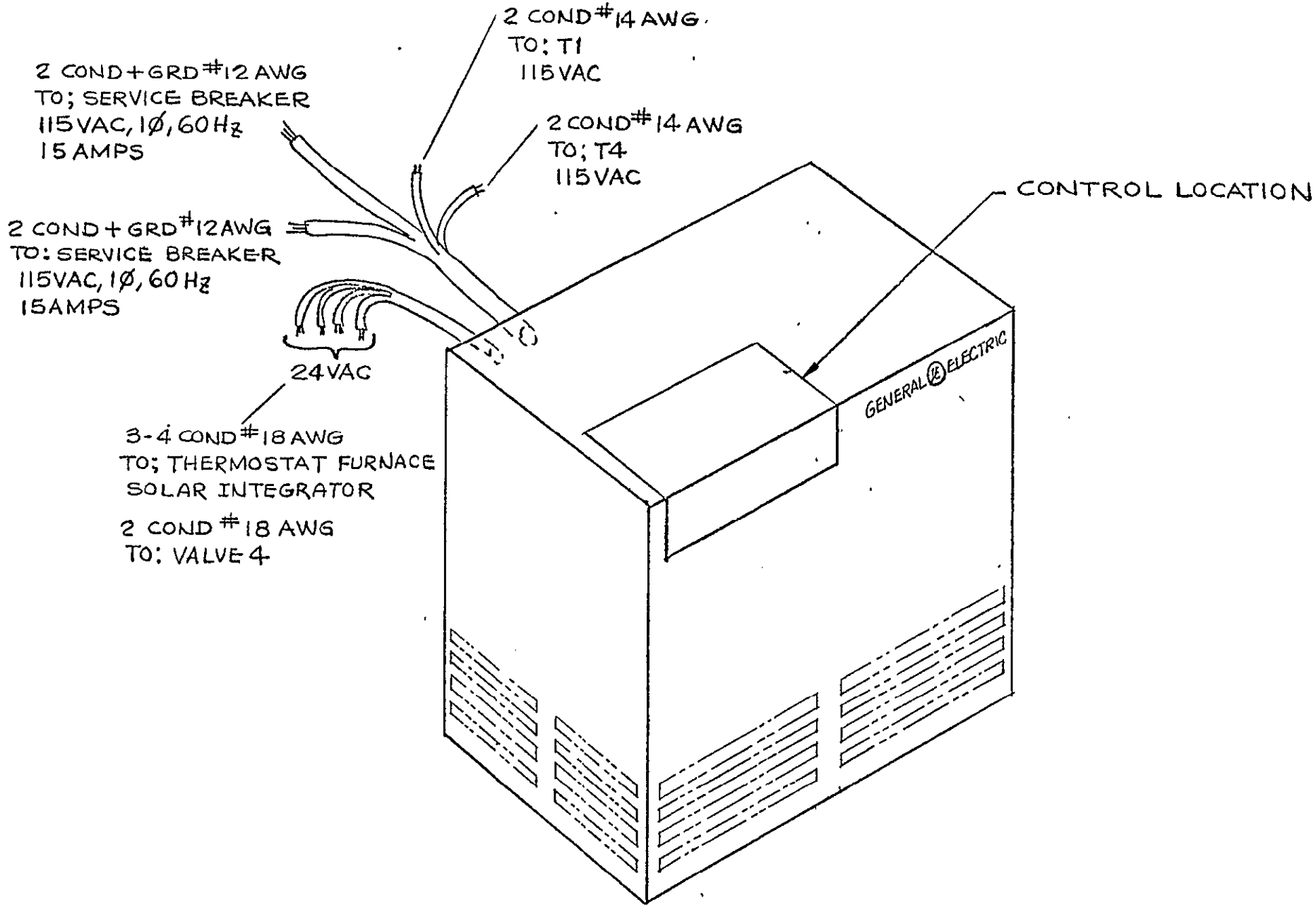

Figure 2.3.1.9-4. Wiring for Fort Meade Site

2.3.1.10 System Integration

During the reporting period, the following significant events took place:

1. The system integration effort on three operational test sites was initiated. The Fort Meade single family-heating only site, the Tullahoma multi-family-heating only site, and the Muscle Shoals-commercial heating only site were all visited. A design concept report was prepared on each and Architect Engineering effort has been initiated.
2. The heating only system level qualification test unit design was completed. The test set up was fabricated and installed in GE's Building B at Valley Forge. The system check out was completed and the qualification test has been initiated. This test facility/set up is currently under test in the heating only mode, but has been designed and fabricated to be converted to the heating and cooling mode when appropriate.
3. Component specifications have been issued covering the full range of system building blocks. Vendor negotiations have been on-going throughout this period to insure the hardware specified can be produced at realistic cost in the required quantities. Certain of those components have been procured and integrated into the system level qualification test set-up.

4. An integrated package, the energy management module, has been designed. This unit will house the following portions of the system:

   - collector loop heat exchanger, HX1
   - collector loop pump, P1
   - collector loop expansion/drain-down tank
   - TES loop pump, P2
   - controls package
   - interconnecting pumping

   This unit is intended to facility system integration by:

   - compact packaging/handling/installation of the above components
   - minimizing plumbing connections at system installation
   - insuring against improper application/matching of the housed components in the field

5. A collector loop test system (of the two collector module size) has been designed, fabricated and installed in GE's Building B, Valley Forge. This test unit is intended to demonstrate the system operating modes of:

   - initial start-up
   - normal energy collection
   - active heat dump
   - emergency drain-down/boil-off/condensing

   These tests are currently underway.

2.3.2 HEATING AND COOLING SYSTEMS (WBS 1.2.2.2)

2.3.2.1 Collectors

Refer to paragraph 2.3.1.1 Development carried out for heating system applies.

2.3.2.2 Energy Storage Subsystem

Refer to paragraph 2.3.1.2. Development of hot TES applies

2.3.2.3 Space Heating/Cooling Subsystem

Use of the heat pump results in different equipment for heating and cooling systems. Activity just starting.

2.3.2.4 Auxiliary Energy Subsystem

Equipment will be different for heating and cooling systems. Activity just starting.

2.3.2.5 Hot Water Subsystem

Refer to paragraph 2.3.1.5. Heating systems work is applicable.

2.3.2.6 Energy Transport Subsystem

Refer to paragraph 2.3.1.6. Heating system work is applicable.

2.3.2.7 Controls Subsystem

2.3.2.7.1 System Design

The system design and control modes were presented at the Heating and Cooling PDR. Because no substantial changes to these operational modes have occurred since PDR, no discussion is presented here.

2.3.2.7.2 Component Design

2.3.2.7.2.1 Sensors. The sensor development items for the Heating Systems (see paragraph 2.2.7.2) are also applicable to the Heating and Cooling Systems. No new sensor development is foreseen for these systems.

2.3.2.7.2.2 System Logic Board and Packaging. No breadboarding, logic design, or packaging design for the Heating and Cooling Systems has been done to date. However, the circuit decisions, packaging layout, and power interface (see paragraph 2.2.7.2) for the Heating Systems shall serve as a baseline for the hardware approach in the Heating and Cooling Systems.

2.3.2.8 Electrical Subsystem - No significant activity during the reporting period.

2.3.2.9 System Integration

See paragraph 2.3.1.10. The system integration effort described in that paragraph is also applicable to cooling systems, recognizing that the specific sites mentioned are heating sites.

2.3.2.10 Cooling Subsystem (WBS 1.2.2.2.11)

The following section addresses the status of the cooling subsystem development effort. These subsystems include 3 ton and 10 ton solar driven heat pump and air conditioner equipment as shown schematically in Figure 2.3.2.10-1 and 2.3.2.10-2. Cycle 1 subsystem hardware analysis, design, fabrication, and test activities continued through this reporting period with the major emphasis on fabrication, test, and test result correlation with analytical performance models. Preliminary analytical modeling of Cycle 2 hardware performance was also initiated based on Cycle 2 design concepts examined last reporting period.

2.3.2.10.1 Subsystem Analysis

Analytical performance models for the low temperature Rankine Engine, and the LTR/HP-AC matched operation were continually upgraded and updated during this reporting period. In addition, measured test data correlation was performed with the analytical models based on initial performance test results. The correlation to date is excellent (within 5%) but is only based on a limited number of measured data points.

2.3.2.10.1.1 Low Temperature Rankine Engine Analysis

Design point cases for the top three Cycle 1 engine configurations were analyzed using the most up to date hardware design information. Key design parameters, performance results, and corresponding engine operating schematics are summarized in Figures 2.3.2.10.1.1-1, 2.3.2.10.1.1-2, and 2.3.2.10.1.1-3. Expander performance models were developed and representative map is shown in Figure 2.3.2.10.1.1-4. These maps were also compared with initial Cycle 1 measured test data and showed, based on a limited number of measured data points, excellent correlation.

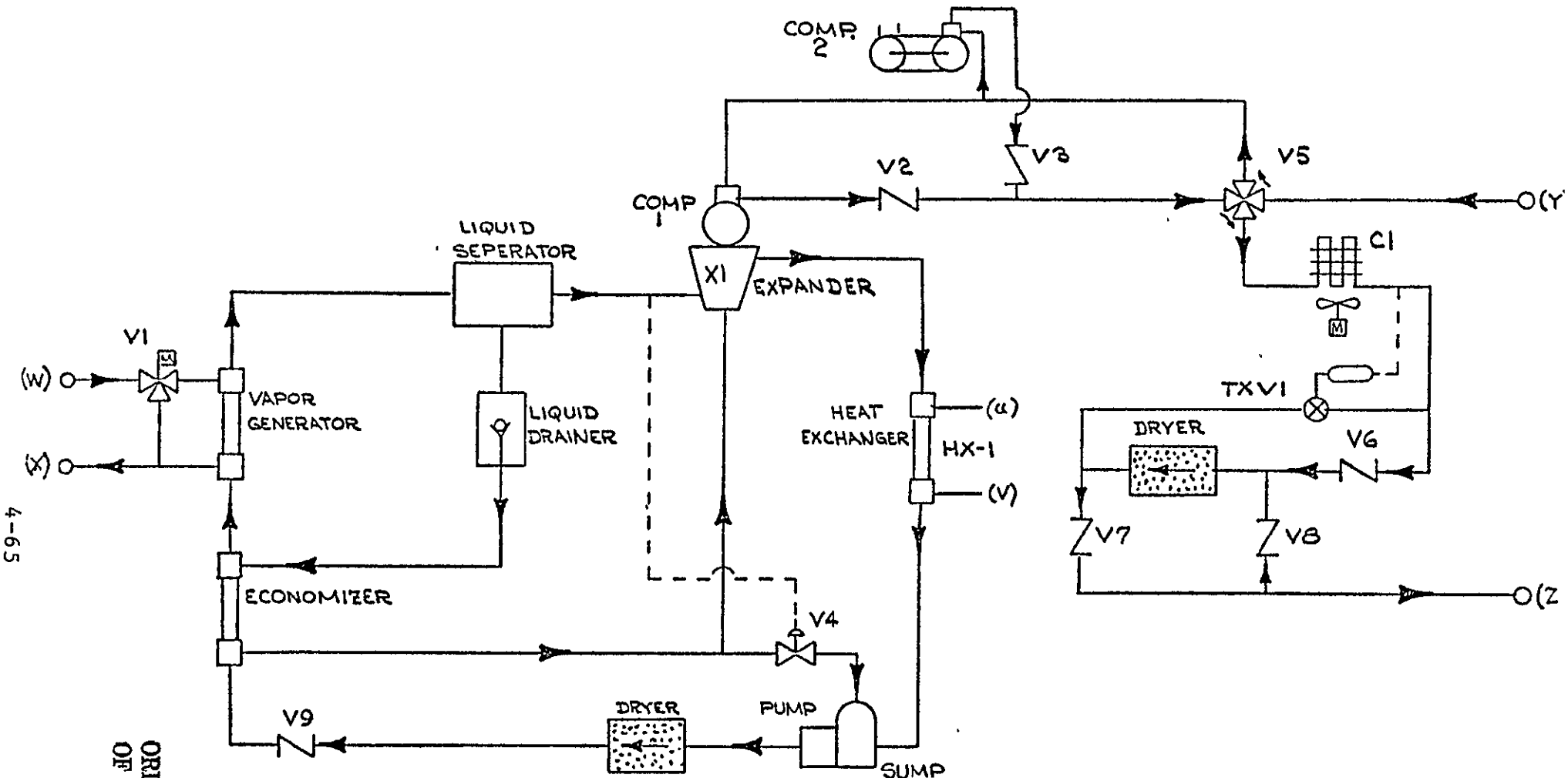

Figure 2.3.2.10-1. Cycle 1, 3 Ton S/EDHP Schematic

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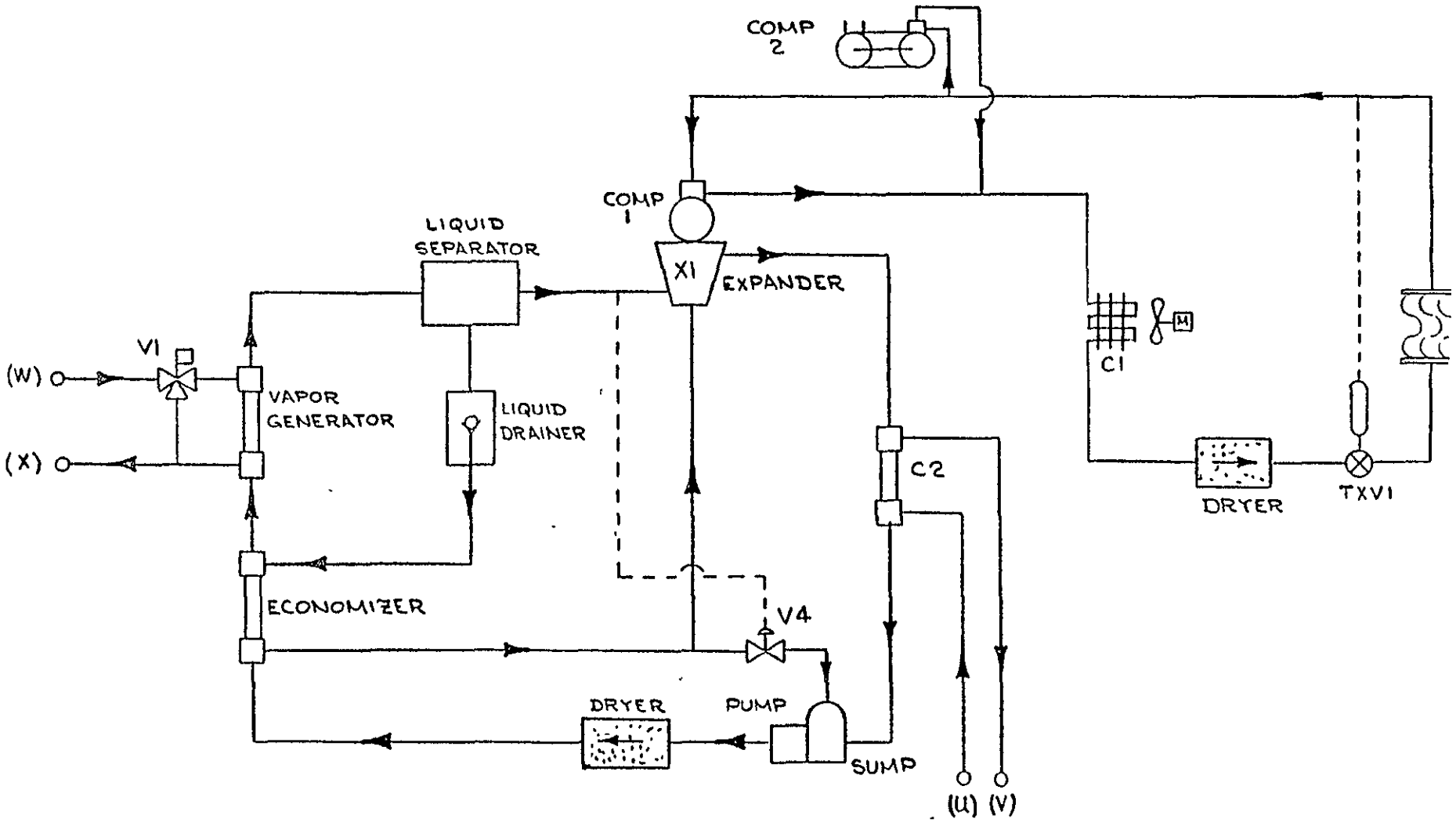
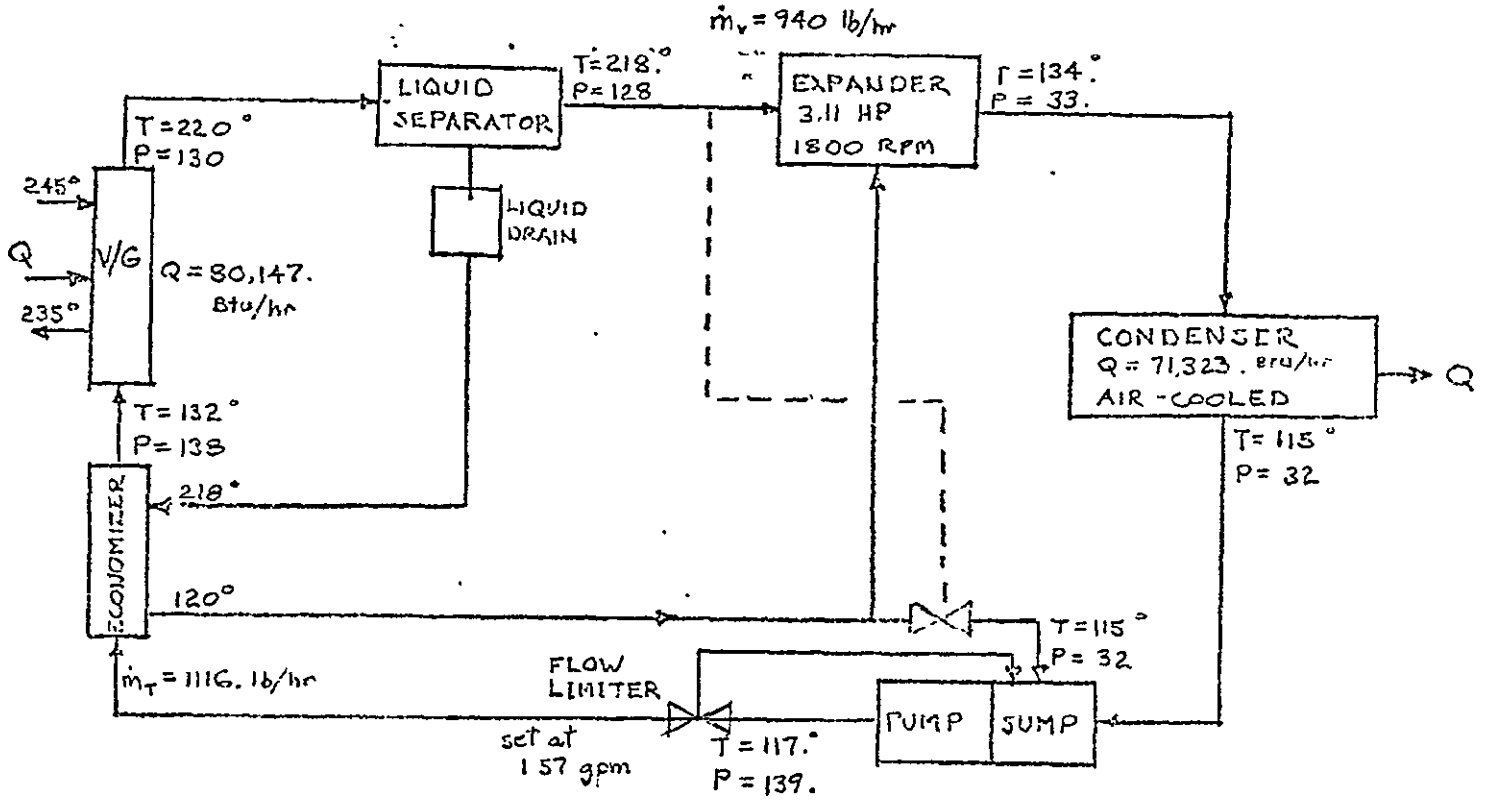


Figure 2.3.2.10-2. Cycle 1, 10 Ton S/E DAC Schematic



3 TON 10 VANE LTR AIR COOLED

V/G R-11 FLOW RATE		:	1116.	lb/hr
V/G WATER INLET FLOW		:	16.	gpm
	TEMP	:	245.	°F
CONDENSING AIR	INLET FLOW	:	6000.	cfm
	TEMP	:	95.	°F.(dry bulb)
EXPANDER	SPEED	:	1800.	rpm
	VAPOR FLOW	:	940.	lb/hr
	POWER	:	3.11	HP
	TORQUE	:	9.09	ft-lb
CYCLE EFFICIENCY		:	9.9	%

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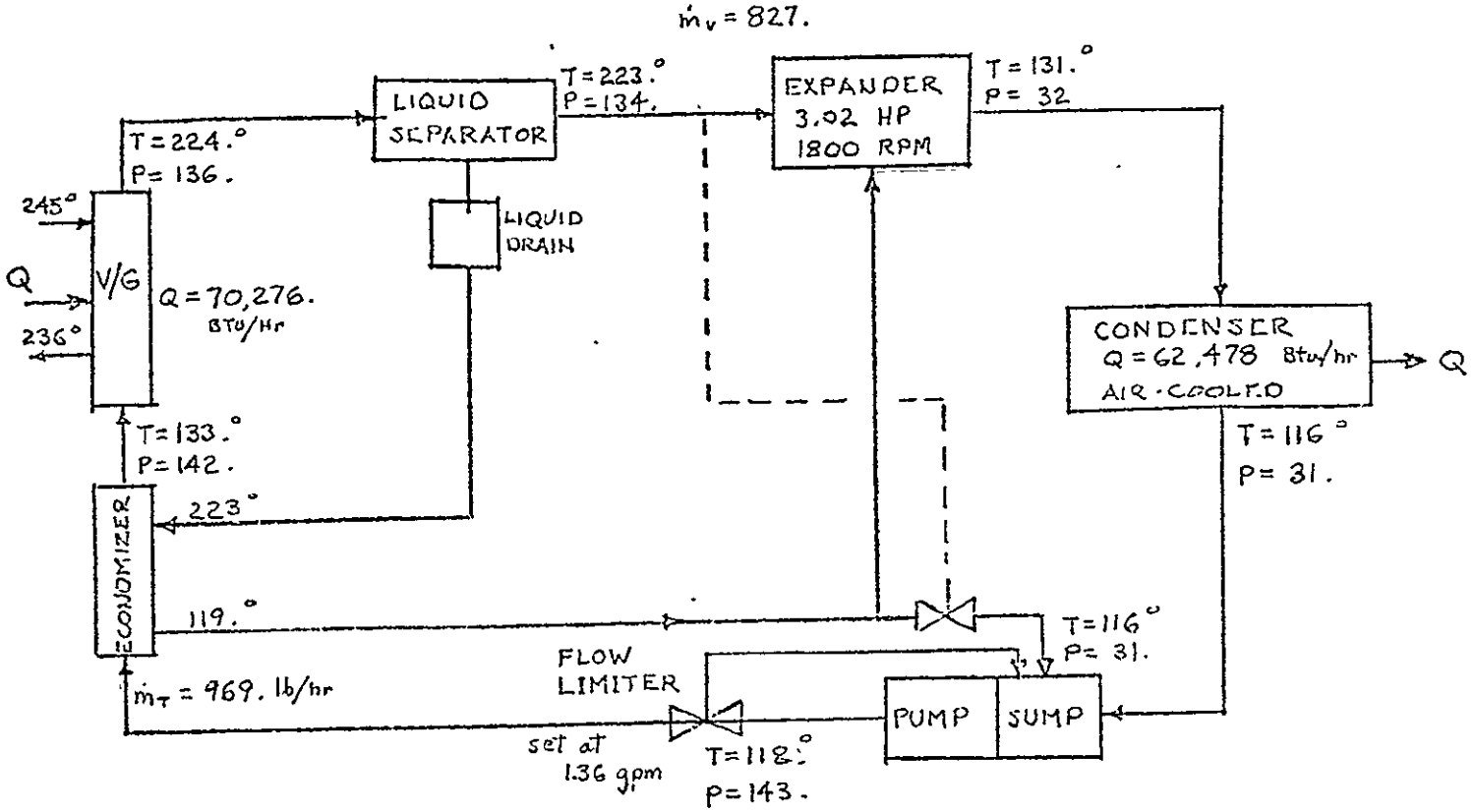
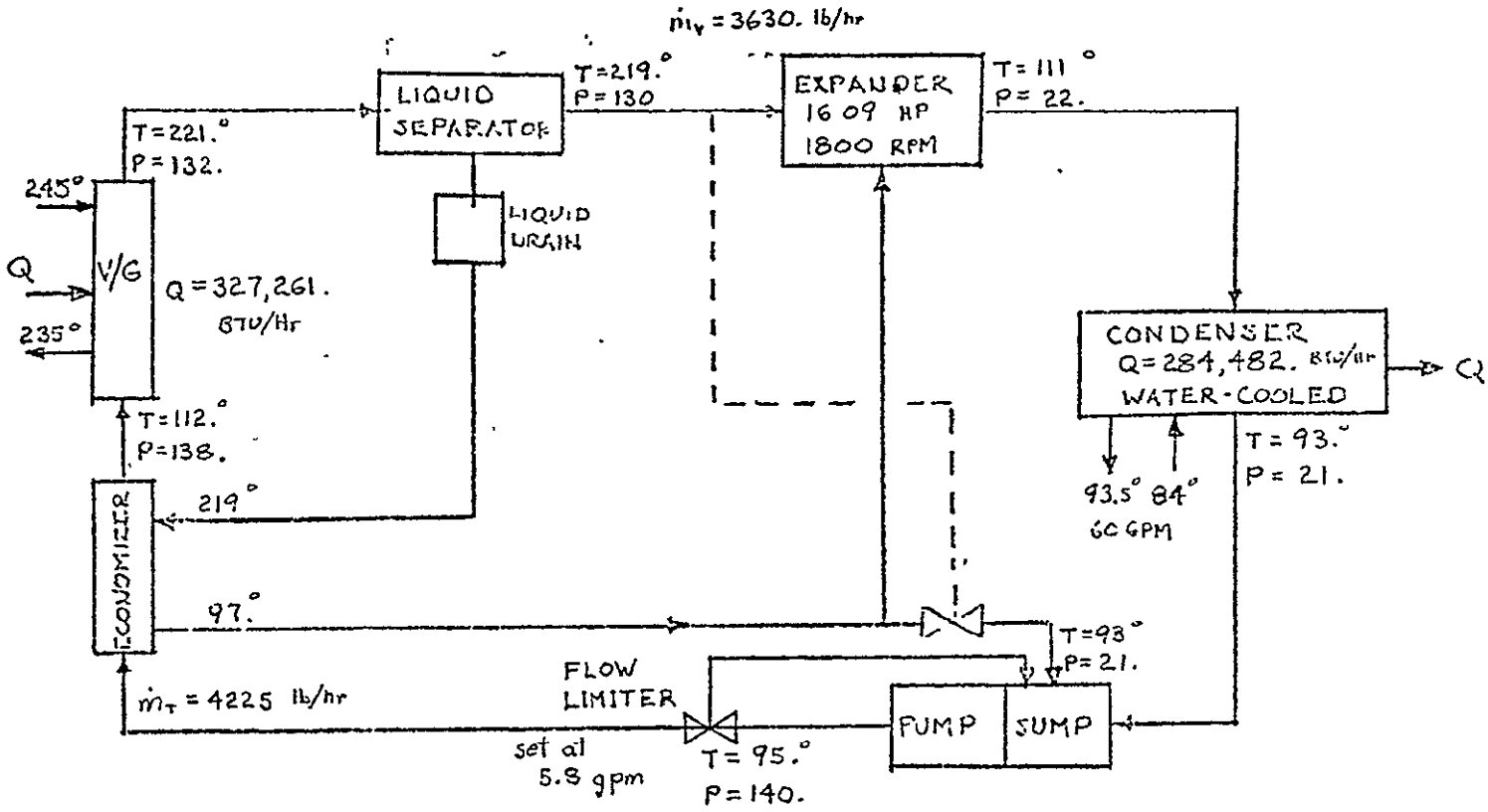
Figure 2.3.2.10.1.1-1. 3-Ton, 10-Vane Air Cooled LTR



3 TON 8 VANE LTR AIR COOLED

V/G R-11 FLOW RATE	:	969.	lb/hr
V/G WATER INLET FLOW	:	16	gpm
TEMP	:	245.	°F.
CONDENSING AIR INLET FLOW	:	6000.	cfm
TEMP	:	95.	°F (dry bulb)
EXPANDER SPEED	:	1800.	rpm
VAPOR FLOW	:	827.	lb/hr
POWER	:	3.02	HP
TORQUE	:	8.82	ft-lb
CYCLE EFFICIENCY	:	10.9	%

Figure 2.3.2.10.1.1-2. 3-Ton, 8 Vane Air Cooled LTR



10 TON 10 VANE LTR WATER COOLED

V/G R-11 FLOW RATE	:	4225.	lb/hr
V/G WATER INLET FLOW	:	64.8	gpm
TEMP	:	245.	°F.
CONDENSING WATER INLET FLOW	:	60.	gpm
TEMP	:	84.	°F (95°F dry bulb 78° F wet bulb)
EXPANDER SPEED	:	1800.	rpm
VAPOR FLOW	:	3630.	lb/hr
POWER	:	16.09	HP
TORQUE	:	46.96	ft-lb
CYCLE EFFICIENCY	:	12.5	%

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Figure 2.3.2.10.1.1-3. 10-Ton, 10-Vane Water Cooled LTR

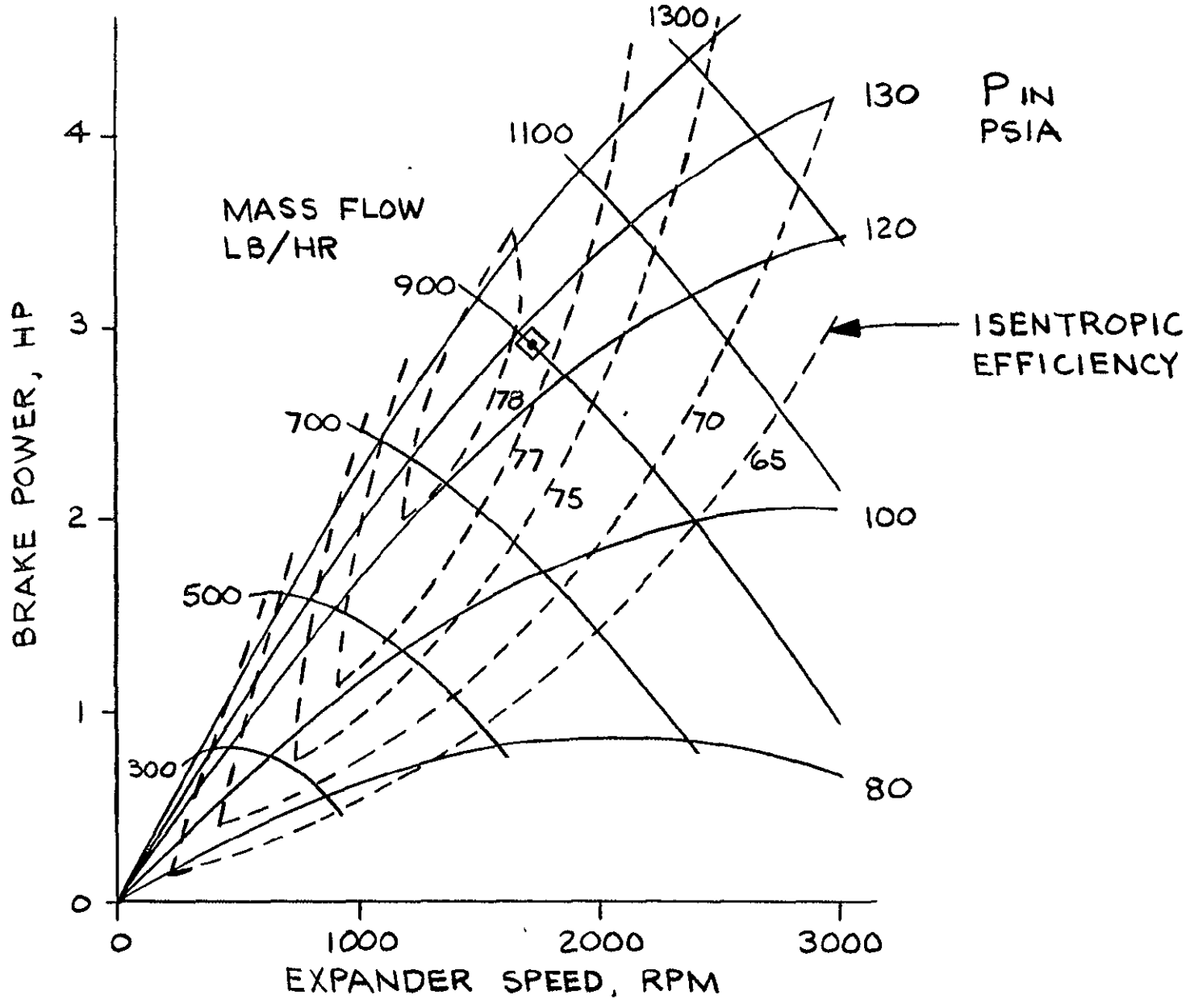

Figure 2.3.2.10.1.1-4. Expander Performance Model Map

2.3.2.10.1.2 S/E' DHP/AC Matched Operation Analyses

Matched operating range and performance analyses were performed for the 3 ton S/E DHP incorporating current Cycle 1 design criteria and test data. The predicted performance is summarized in the series of operating footprints depicted in Figure 2.3.2.10.1.2-1. Similar analyses has been initiated for the 10 ton S/E DAC.

2.3.2.10.2 S/E DHP-AC

2.3.2.10.2.1 Expander

2.3.2.10.2.1.1 10 Ton, 10 Vane, Horizontal Expander

Fabrication and assembly of the two Cycle 1, 10 ton, 10 vane, horizontal expanders was completed without any significant manufacturing problems. The assembled Cycle 1 expander is shown in Figure 2.3.2.10.2.1.1-1. Unit 1 was built with grease packed bearings for initial testing. In less than 4 hours of operation at light load operating conditions the R-11 had completely washed the grease from the bearings. An evaluation of alternate self-lube bearings was initiated and is underway. To continue testing, oil lubricated bearings were installed. The first phase of testing was successfully completed. This involved the determination of the rotor to end plate clearance which optimized power output. The second phase of testing, performance characterization, is now underway with initial results (Ref. Fig. 2.3.2.10.2.1.1-2) indicating that expander performance is right on target with earlier analytical predictions. This early correlation is significant in that it tends to verify the expander analytical scaling laws; one of the key objectives in building Cycle 1, 10 ton expander hardware. Further testing is planned to fully substantiate the validity of the scaling laws. To date, the first expander, since

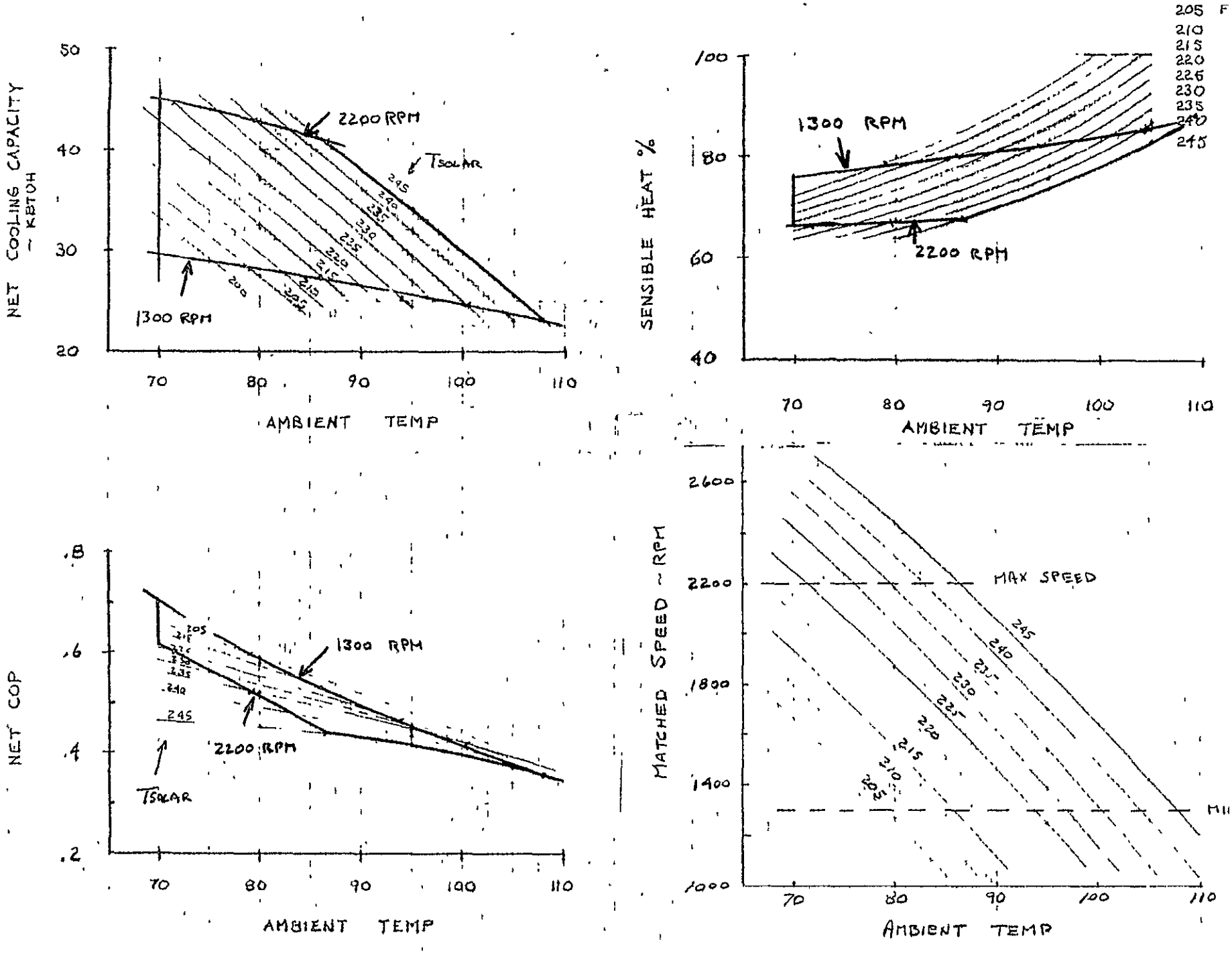

Figure 2.3.2.10.1.2-1 3 -Ton LTR/HP Matching

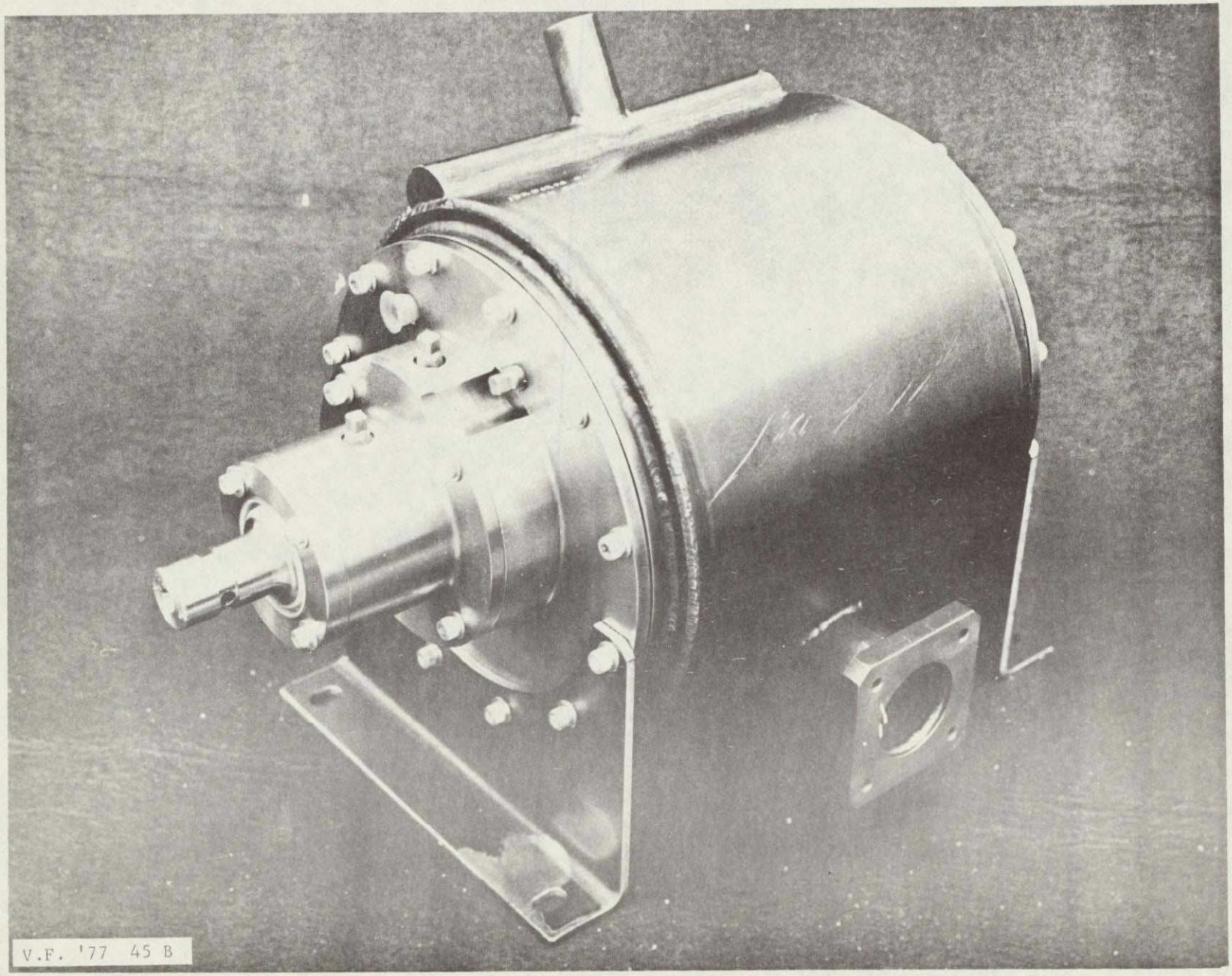

Figure 2.3.2.10.2.1.1-1. Cycle 1, 10 Ton Expander

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	PT.1	PT.2	PT.3
MASS FLOW	2450 LBM/HR	3200 LBM/HR	3200 LBM/HR
INLET PRESSURE	110 PSIA	120 PSIA	130 PSIA
CONDENSING PRESSURE	21 PSIA	21 PSIA	21 PSIA
SPEED	1400 RPM	1675 RPM	1500 RPM
PREDICTED HP	9.0	12.4	13.2
MEASURED HP	8.9	12.4	12.8

Figure 2.3.2.10.2.1.1-2. Cycle 1, 10-Ton, 10-Vane Expander Performance

incorporating the oil lubricated bearings, has accumulated 24 hours of actual running time with no significant problems. Performance testing will continue until the expander is characterized throughout it's expected operating range. A second Cycle 1, 10 ton, 10 vane, horizontal expander has been built and will be tested to verify repeatability of build and performance.

2.3.2.10.2.1.2 3 Ton, 10 Vane, Vertical Expander

Fabrication and assembly of the three Cycle 1, 3 ton, 10 vane, vertical expanders has been completed with no major manufacturing problems experienced. An assembled Cycle 1, 3 ton expander on test is shown in Figure 2.3.2.10.2.1.2-1. Based on initial problems with grease packed bearings in the Cycle 1, 10 ton expander, the first Cycle 1, 3 ton expander was initially tested with an oil lubricated bearing system. Early test results (Ref. Fig. 2.3.2.10.2.1.2-2) correlate well with the analytical predictions. This early correlation is significant in that it tends to verify our ability to accurately predict the vertical mounting configuration performance. Further testing, however, will be required to fully substantiate this. The first expander has accumulated 1 hour of actual running time to date. Problems have been experienced with vane breakage during early testing. Design corrections have been initiated.

2.3.2.10.2.1.3 3 Ton, 8 Vane, Vertical Expander

The 3 ton, 8 vane, vertical expander design was released and fabrication is on schedule.

2.3.2.10.2.2 Feed Pump

2.3.2.10.2.2.1 3 Ton, Double Stage Feed Pump

Fabrication, assembly, and performance testing of two Cycle 1,3 ton double stage feed pumps has been completed. Test results are presented in Figure 2.3.2.10.2.2.1-1.

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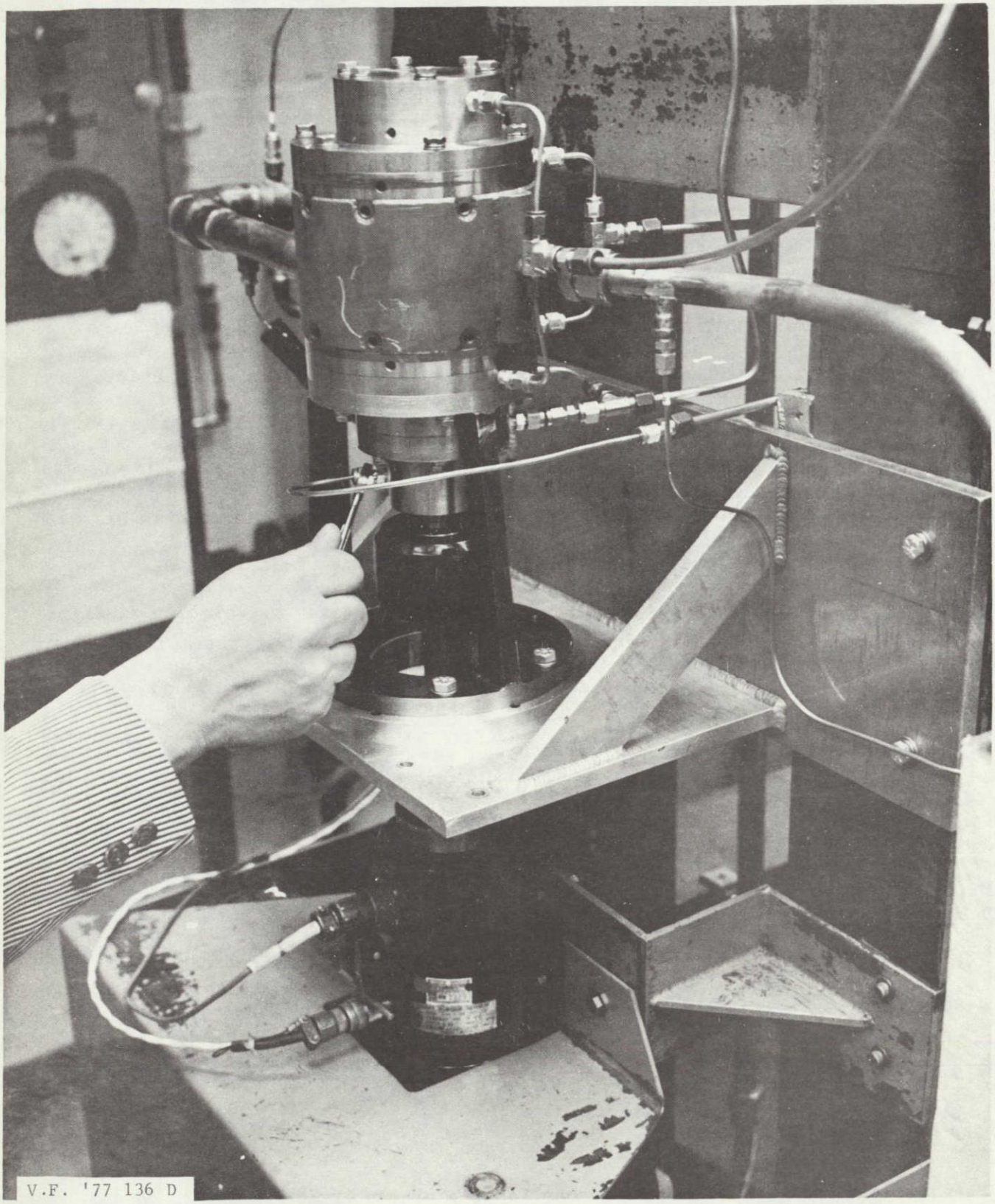

Figure 2.3.2.10.2.1.2-1. Cycle 1, 3-Ton Expander on Test

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C-2

	PT. 1
MASS FLOW	900 LBM/HR
INLET PRESSURE	127 PSIA
CONDENSING PRESSURE	33 PSIA
SPEED	1740 RPM
PREDICTED HP	2.92
MEASURED HP	3.00

Figure 2.3.2.10.2.1.2-2. Cycle 1, 3-Ton, 10-Vane Expander Performance

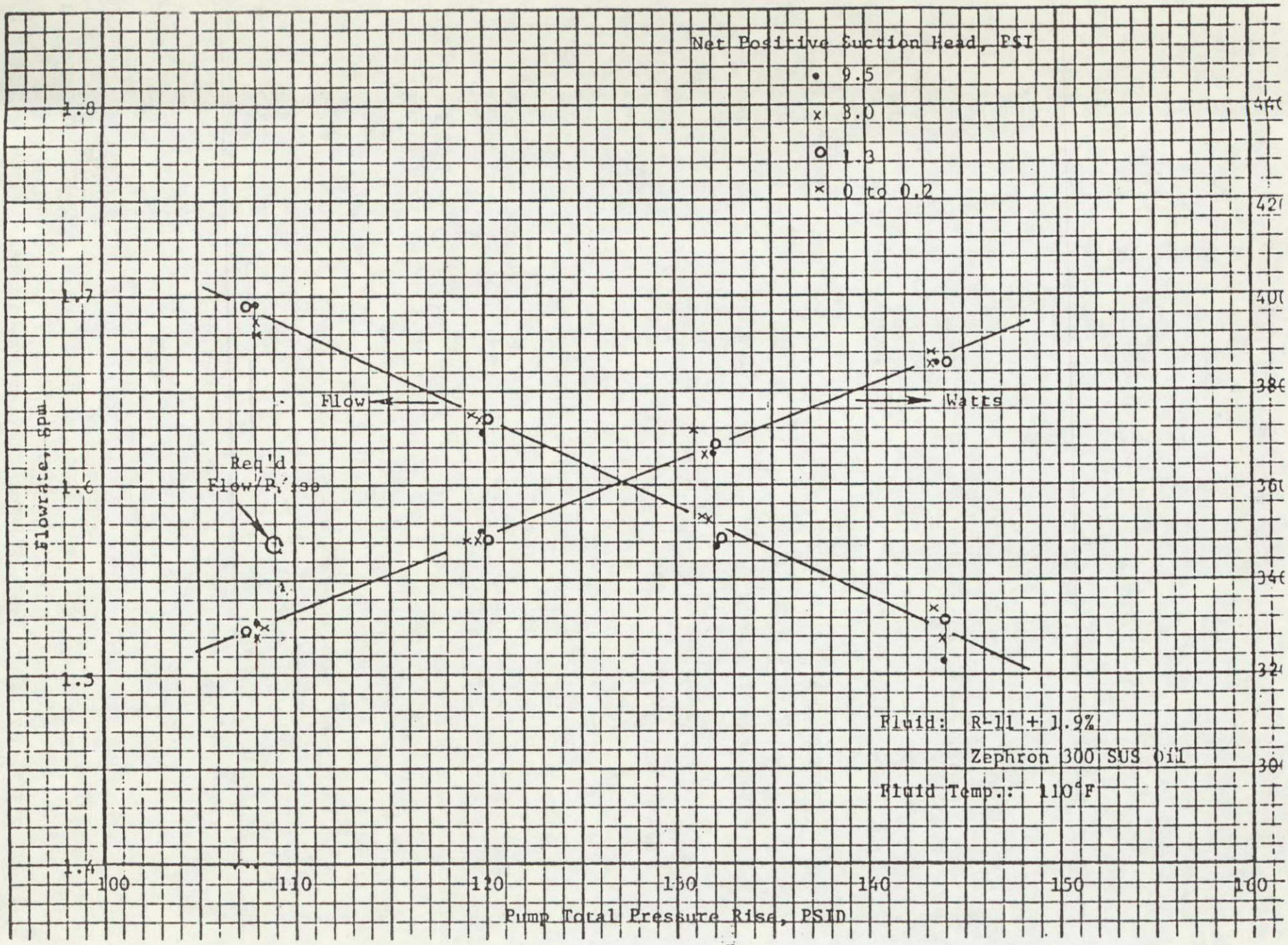

Figure 2.3.2.10.2.2.1-1. Cycle 1, 3-Ton Double Stage Feed Pump Performance

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Cycle 2 design concepts have been initiated.

2.3.2.10.2.2.2 10 Ton Double Stage Feed Pump

Fabrication, assembly, and performance testing of two Cycle 1, 10 ton double stage feed pumps has been completed. An assembled Cycle 1, 10 ton double stage feed pump is shown in Figure 2.3.2.10.2.2.2-1. Test results are presented in Figure 2.3.2.10.2.2.2-2. Cycle 2 design concepts have been initiated.

2.3.2.10.2.2.3 Variable Volume Vane Pump

An alternate Cycle 1 feed pump design was identified; the variable volume vane type. A sample pump of this type has been received from Continental Pump. The freon feed pump test facility has been modified to accept this pump and testing is planned to start next report period.

2.3.2.10.2.3 Heat Exchangers

2.3.2.10.2.3.1 3 Ton, Vapor Generator

Two Cycle 1, 3 ton vapor generators have been fabricated and assembled and are in the process of being proof tested. A picture of Cycle 1, 3 ton vapor generator components is shown in Figure 2.3.2.10.2.3.1-1. Performance characterization testing is planned to begin next report period.

2.3.2.10.2.3.2 10 Ton Vapor Generator

Two Cycle 1, 10 ton vapor generators have been fabricated and are in the assembly cycle. Performance testing is planned to begin next report period.

2.3.2.10.2.3.3 Condensers

Cycle 1 condensers have been purchased from Dunham-Bush and are being installed in the test loops with test start planned next report period.

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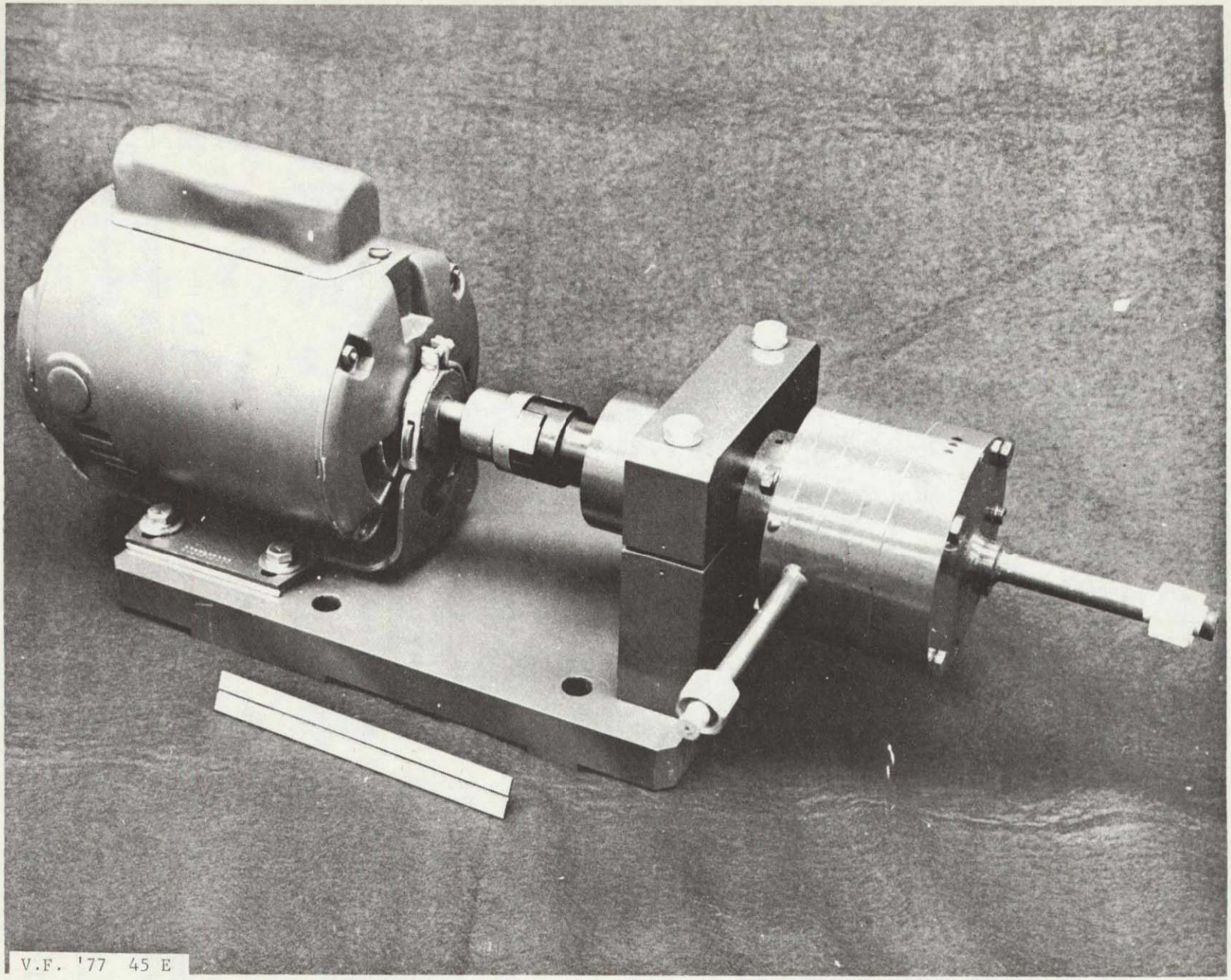

Figure 2.3.2.10.2.2.2-1. Cycle 1, 10-Ton Double Stage Feed Pump

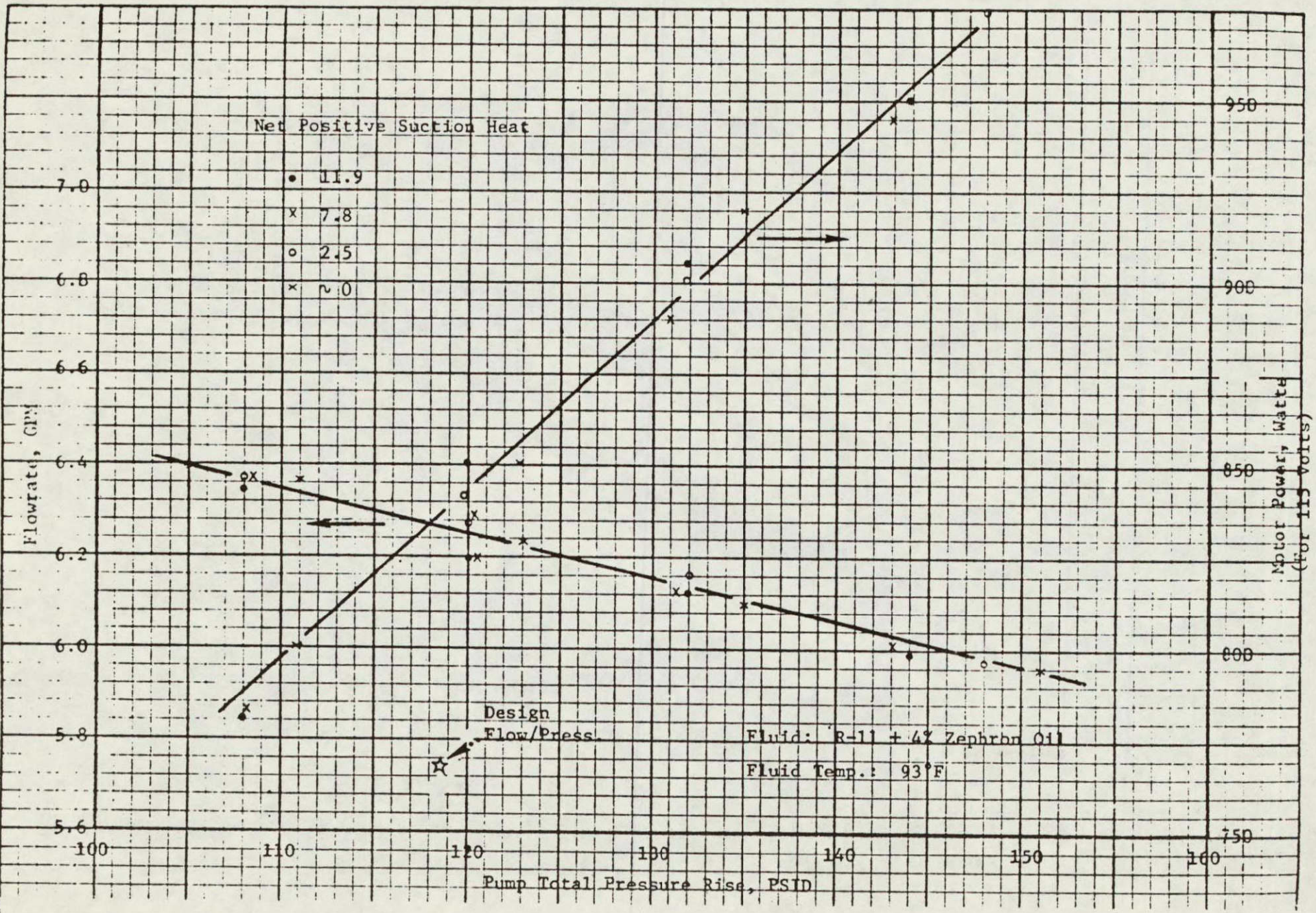

Figure 2.3.2.10.2.2.2.-2. Cycle 1, 10-Ton Double Stage Feed Pump Performance

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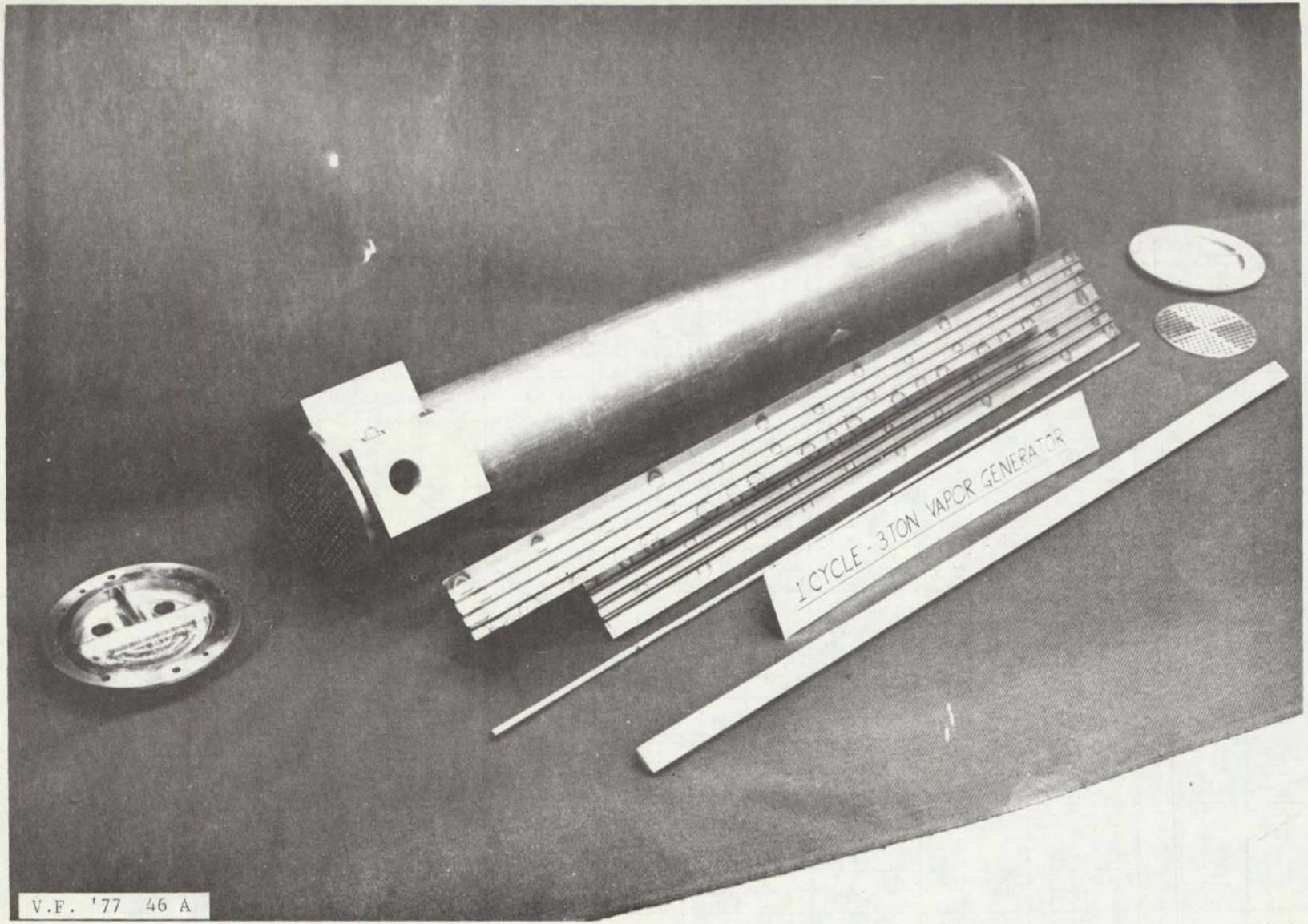

Figure 2.3.2.10.2.3.1-1. Cycle 1, 3-Ton Vapor Generator

2.3.2.10.2.3.4 Economizers

Cycle 1 economizers have been purchased from Packless and are in-house. Testing is planned to start next report period.

2.3.2.10.2.4 Solar Driven Compressor

2.3.2.10.2.4.1 3 Ton Solar Driven Compressor

Fabrication, assembly, and performance testing of the Cycle 1, 3 ton solar driven compressors has been completed. Calorimeter performance test results are presented in Figure 2.3.2.10.2.4.1-1. Endurance, low speed lubrication and oil equalization testing was initiated. Preliminary Cycle 2 compressor performance goals were established.

2.3.2.10.2.4.2 10 Ton Solar Driven Compressor

Fabrication, assembly, and performance testing of the Cycle 1, 10 ton solar driven compressors has been completed. Calorimeter performance test results are presented in Figure 2.3.2.10.2.4.2-1. Preliminary Cycle 2 compressor performance goals were established.

2.3.2.10.2.5 Heat Pump/Air Conditioner

2.3.2.10.2.5.1 3 Ton Heat Pump

Three Cycle 1, 3 ton heat pumps have been fabricated, assembled, and one unit has been tested. Test results are presented in Figure 2.3.10.2.5.1-1. Preliminary Cycle 2 heat pump performance goals were established

2.3.2.10.2.5.2 10 Ton Air Conditioner

Three Cycle 1, 10 ton air conditioners have been fabricated, two units assembled, and one unit tested. Test results are presented in Figure 2.3.10.2.5.2-1. Preliminary Cycle 2 air conditioner performance goals were established.

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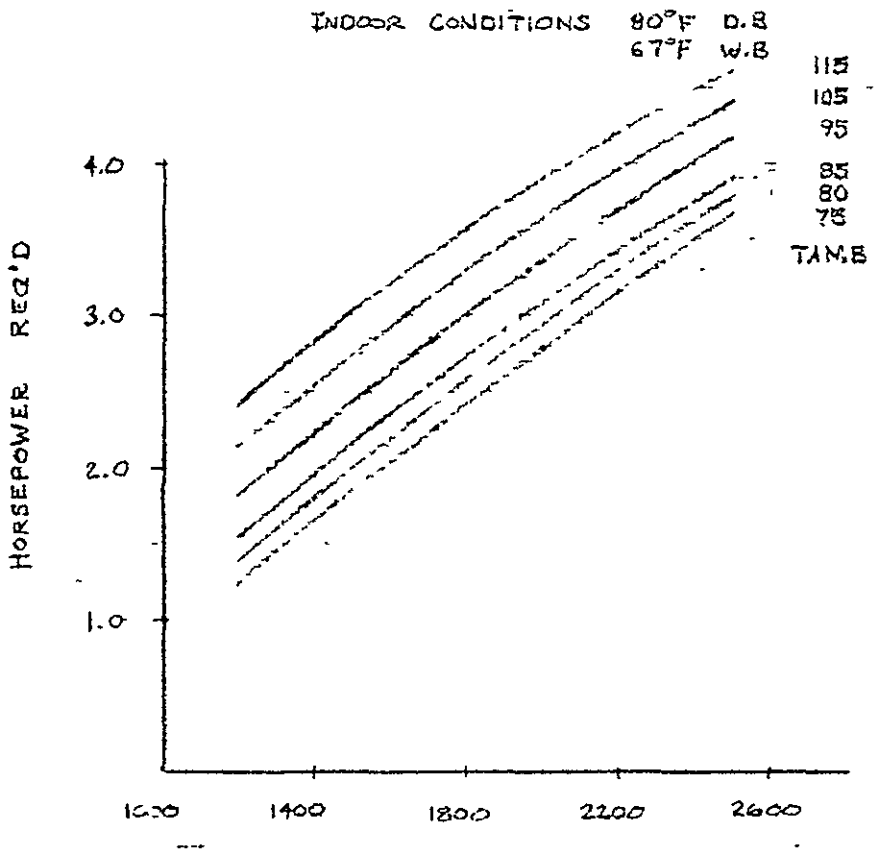

Figure 2.3.2.10.2.4.1-1. Cycle 1, 3-Ton Solar Driven Compressor Performance

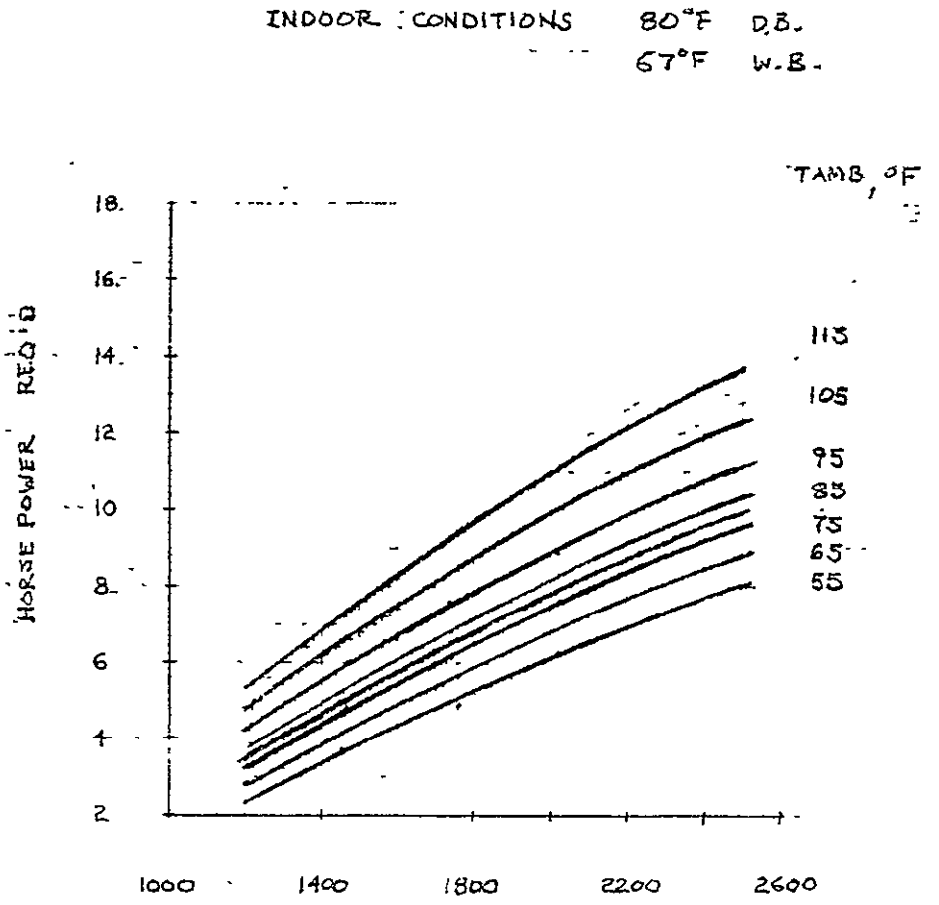

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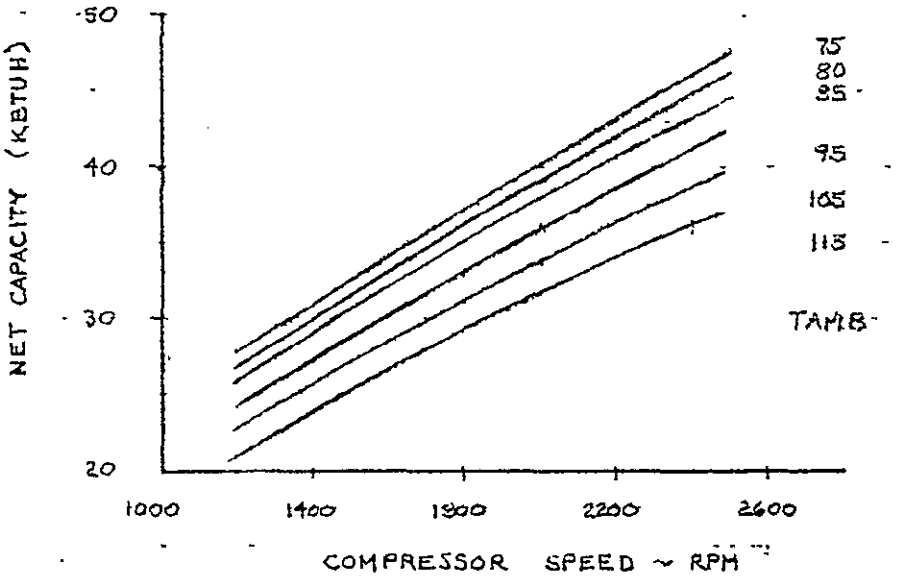
Figure 2.3.2.10.2.4.2-1. Cycle 1, 10-Ton Solar Driven Compressor Performance



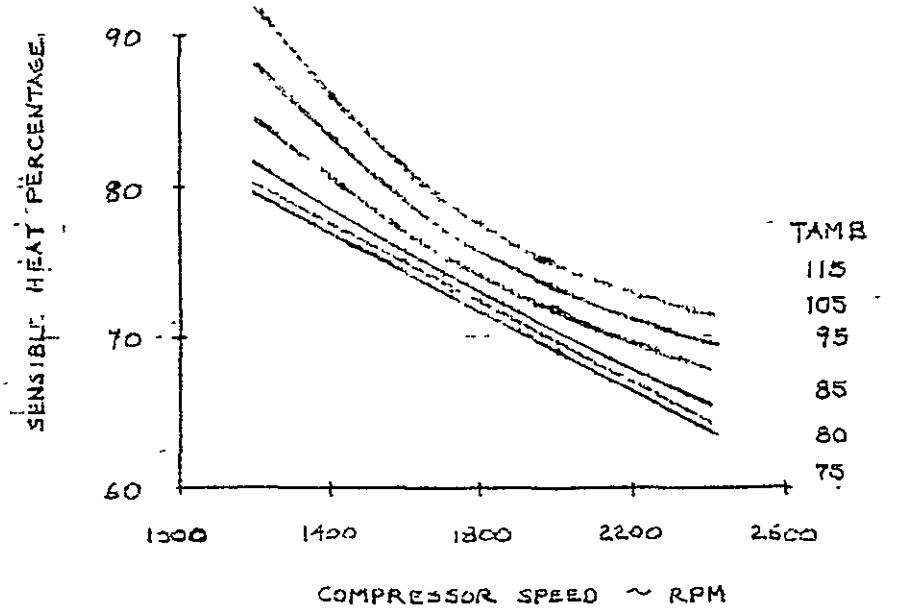
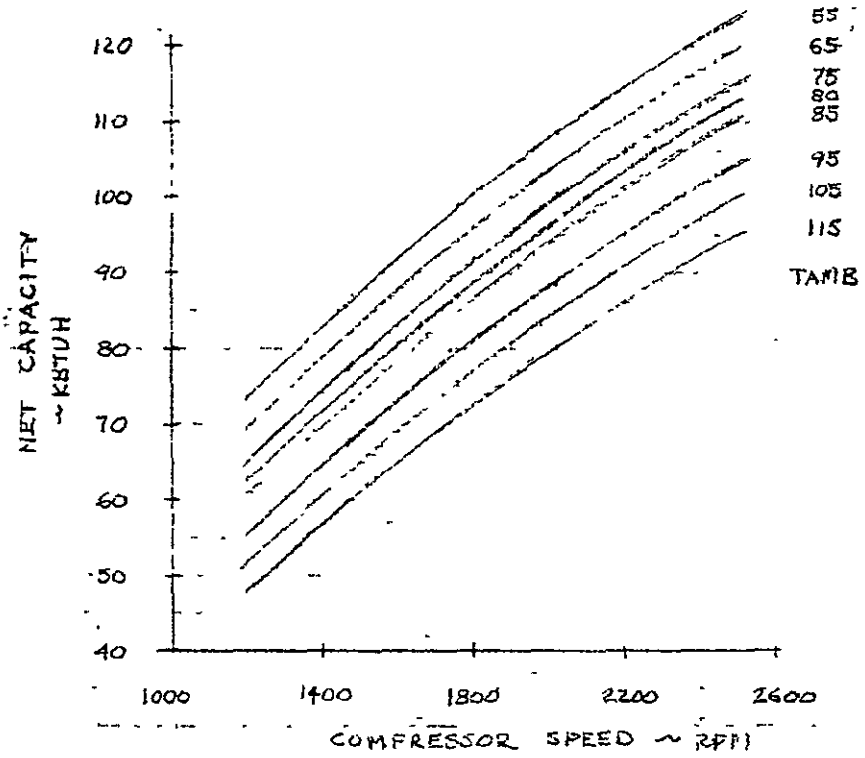


Figure 2.3.10.2.5.1-1. Cycle 1,3-Ton Heat Pump Solar Driven Performance



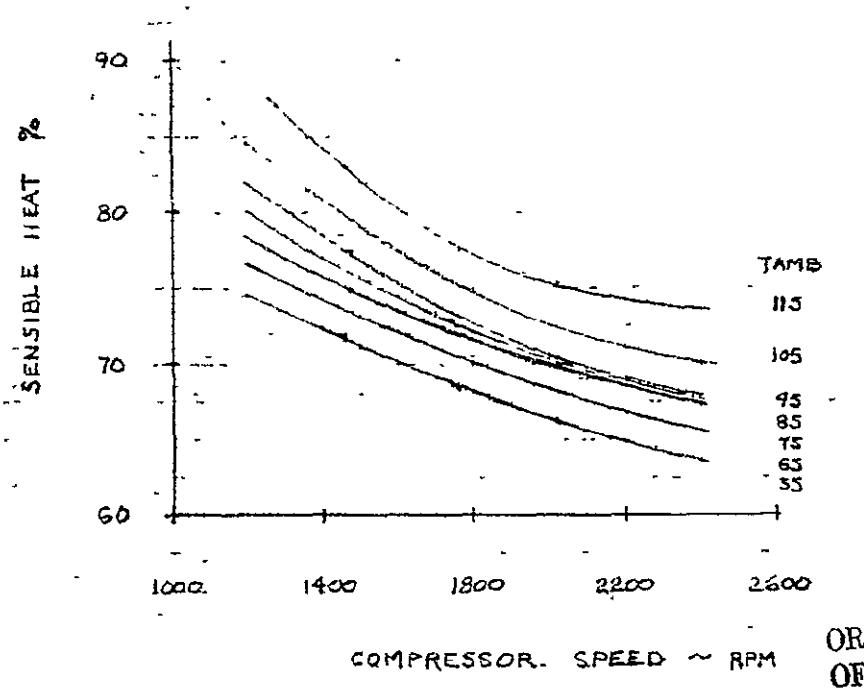


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Figure 2.3.10.2.5.2-1. Cycle 1, 10-Ton Heat Pump Solar Driven Performance

2.3.2.10.2.6 Controls

The controls design for the 3 Ton solar/electric driven heat pump, and the 10 ton solar/electric driven air conditioner was started in the last quarter. The controls package will be an electronic/electro-mechanical design which will control all rankine loop and refrigeration loop components in solar cooling, electric cooling and electric heating.

The electronic logic provides a sequenced start cycle for the solar rankine loop in cooling and locks out electric cooling until solar cooling has been attempted. The sequence logic also prevents heat-to-cool or cool-to-heat operation for a fifteen minute period. The electronic logic also provides safety shutdown logic, solar compressor speed limit control and auxiliary heat energization.

Some of the control sensors which will be used are a magnetic speed sensor, an ambient temperature RTD and a solar inlet water temperature RTD in addition to the standard 2 stage room thermostat. All interface power to components will be through relay contacts, isolating the 24 volt A.C. power and D.C. logic power from 230 volt line power.

2.3.2.10.2.7 Packaging

Cycle 1 packaging concepts are essentially the same as previously reported.

2.3.2.10.2.7.1 3 Ton LTR Package

The Cycle 1, 3 ton LTR package structural design was released and is in the fabrication cycle. The piping design is scheduled for release early next report period. Cycle 2 packaging concepts were initiated.

2.3.2.10.2.7.2 10 Ton LTR Package

The Cycle 1, 10 ton LTR package structural design was released and fabrication will follow the 3 ton structural design. The piping design was initiated and design release is scheduled early next report period. Cycle 2 packaging concepts were initiated.

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2.4 TEST

Test planning is proceeding at all levels of component, subsystem and system for the heating and cooling configurations.

2.4.1 Low Temperature Rankine Component Test Loops

Refurbishment of two of the four existing facilities for Low-Temperature Rankine (LTR) component testing was completed during this reporting period. As reported earlier, four complete and separate LTR component test loops will be available on a full-time basis to support the development of the LTR components throughout the life of the program. The two completed loops are designated the "A"-Loop, one 3-ton loop (3A) and one 10-ton loop (10A). Figure 2.4-1 serves as a representative schematic for the 3A or 10A test loops. The 3A test stand provides for mounting the expander with the shaft vertical as shown in Figure 2.4-2. The 10A test stand provides for horizontal mounting of the expander as shown in Figure 2.4-3.

The "B" test loop, 3B and 10B, are under construction and scheduled for completion May 13, 1977. Both "B" test stands will provide for vertical mounting of the expander as shown for the 3A test stand. Schematically, the "B" loops are essentially the same as for the "A" loops. Changes worth noting are the addition of two turbine flow meters in the R11 loop to measure directly lube flow and pump by-pass flow. Learning type changes include valve changes to improve flow setting of the hot and cold water supplies and additional drains to facilitate cleaning of the loops.

Problems encountered in the checkout and operation of the "A" loops have delayed tests of the 3-ton and 10-ton expanders. The first step in loop

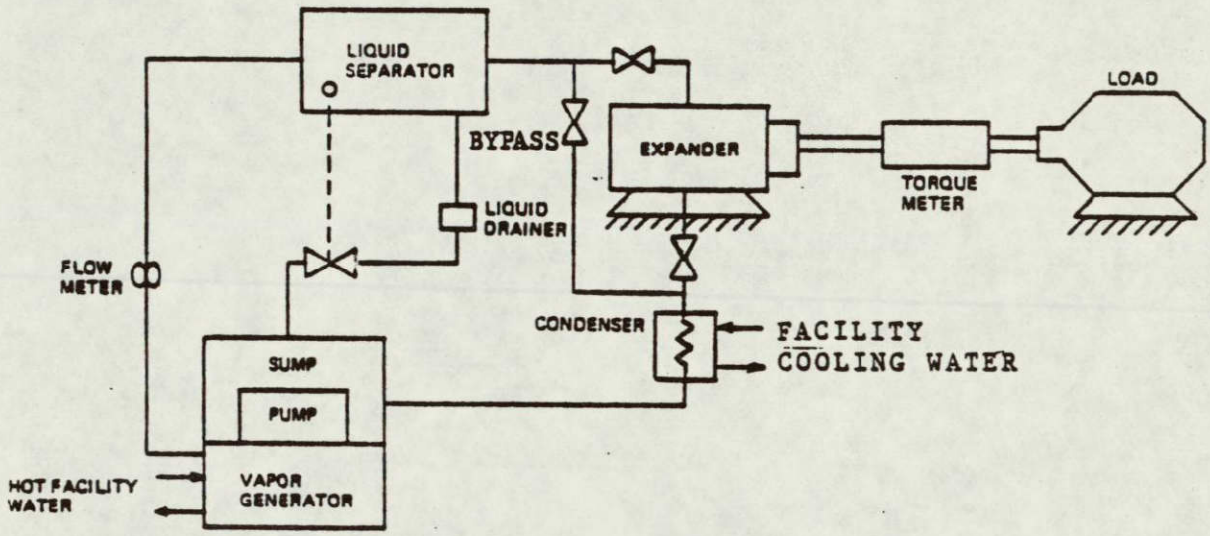

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Figure 2.4-1. LTR Test Loop

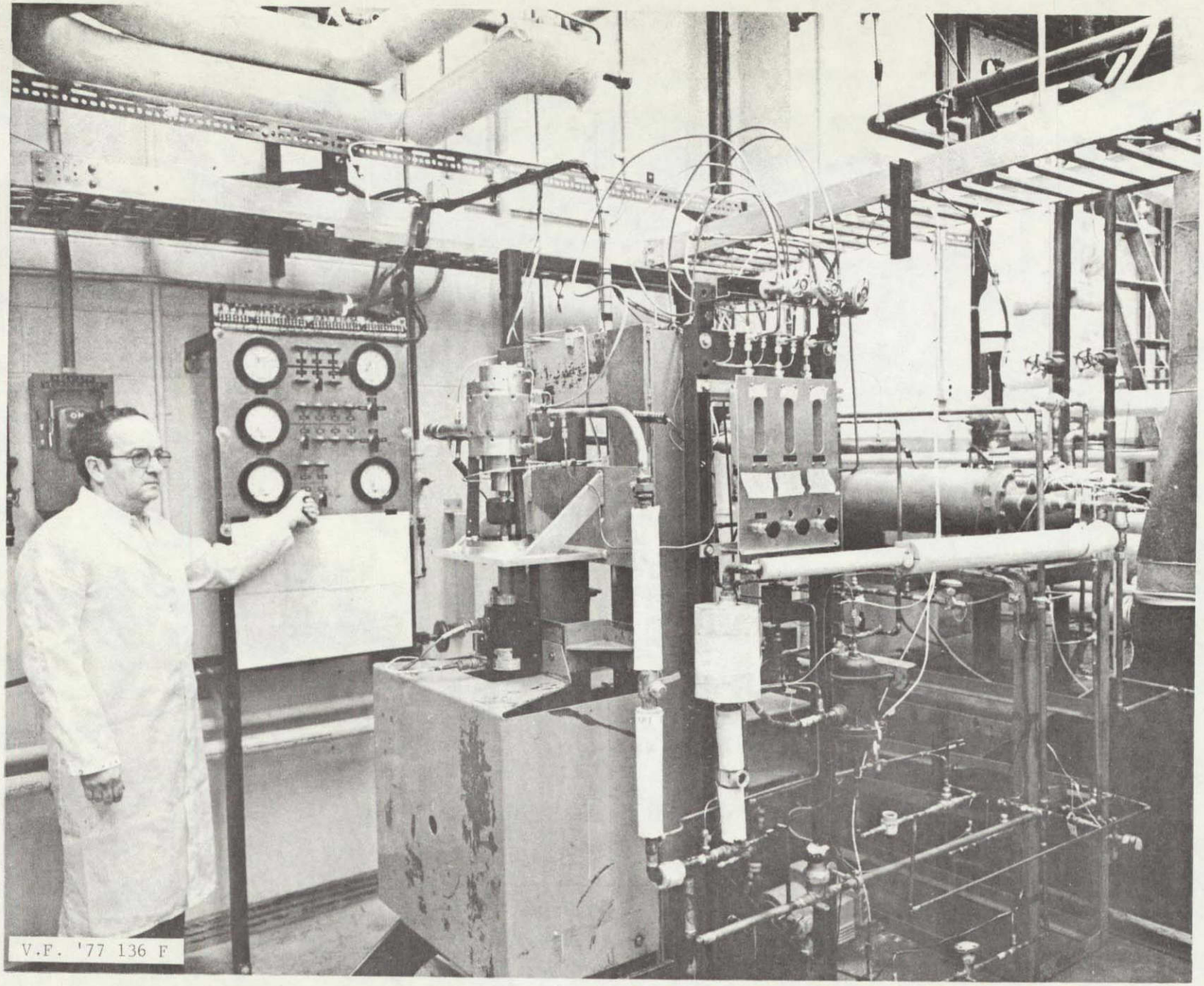

Figure 2-4-2. 3A EXPANDER TEST STAND

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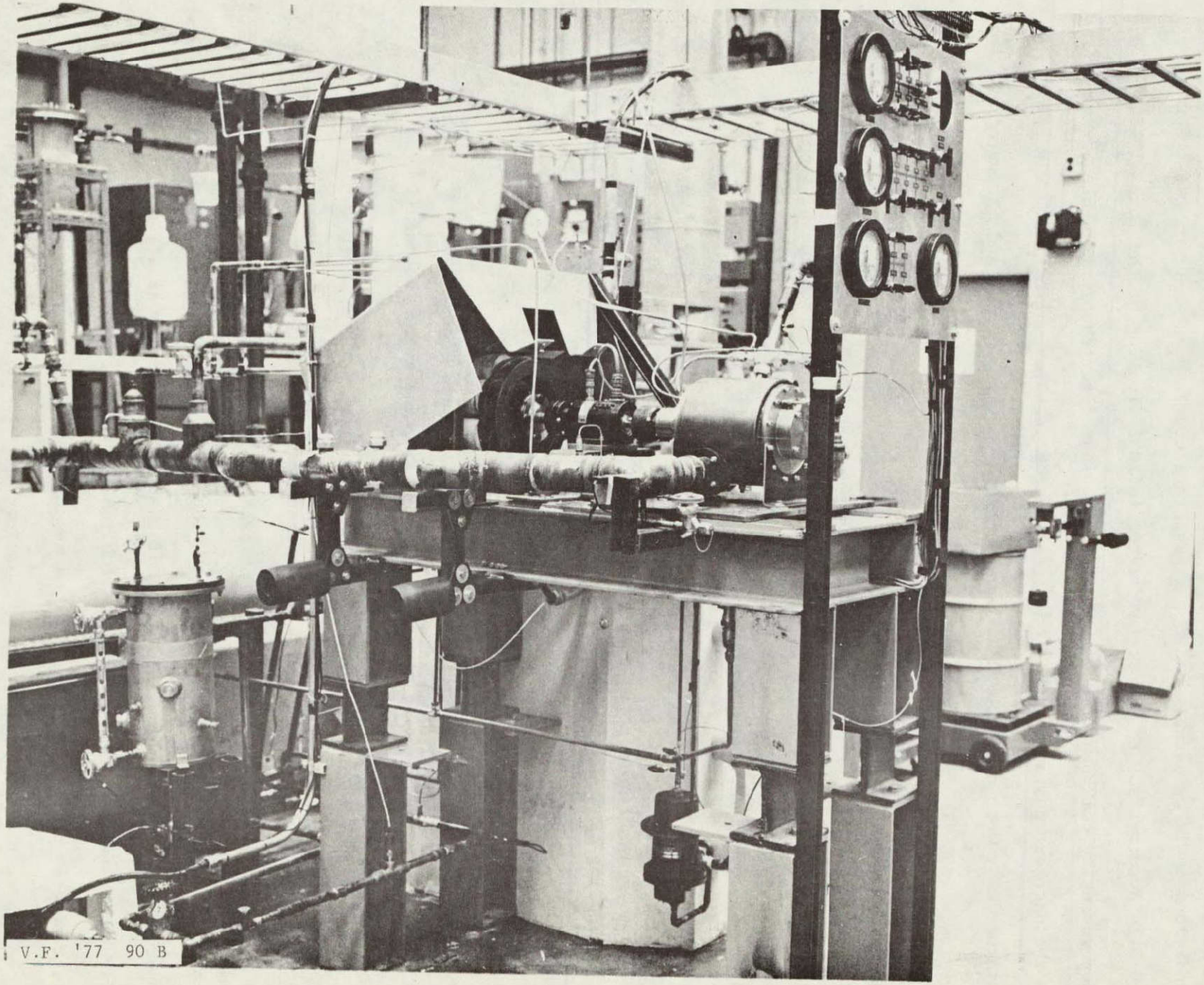

Figure 2-4-3. 10A EXPANDER TEST STAND

operation was to establish operating procedures and assure that controlled conditions could be established for expander testing. Management of the freon and oil inventory was the first task after initial flushing of the loops. The loop was using components identical to those planned for the first cycle engine so the checkout was a verification of design concepts for the engine. Several days of delay were encountered as modifications to the plumbing and hardware were required. The 10-ton expander was available first and effort was concentrated on the 10A loop. Testing efficiency will be improved after completion of the tempered water facility as currently control is accomplished by regulating the flow of facility water which is much colder than normal condensing temperatures.

There have been a series of problems with the facility feed pumps. Freon is a difficult fluid to pump and the difficulty is increased when there is a low head on the suction side of the pump. With this condition plus a minimum amount of subcooling of the liquid to be pumped, cavitation is a problem. For these reasons a development for the engine feed pump was undertaken and hardware has been delivered. These pumps have been installed in the facility test loops because they offer the potential of better performance than the several units tried in the facility to date. The 10A loop has been successfully run with the development pump.

Good heat balances require very accurate measurements in these loops as temperature differences are small. For example, a 1.0 degree error in temperature measurement introduces a 10% error in the heat input on the water side of the vapor generator. The freon comes out of the vapor generator as a two phase mixture and accuracy is required to establish fluid properties. There are discrepancies between the heat flow as measured on the water side and freon side with current attention being focused on the water side measurements of the vapor generator. Though these problems do not invalidate expander test

results to date tests of other components require consistent data in this area. Delays in testing have been encountered due to resolution of this problem.

2.4.2 Heating and Cooling Test Facility

The System Test Facility for the 3-ton and 10-ton heating and cooling systems is shown in Figure 2.4-4. The outdoor cooling tower shown on the left in the figure is in place and the distributor piping to the LTR loops and the 3-ton and 10-ton environmental rooms is presently proceeding on schedule. The 30-ton mechanical refrigeration chiller, shown schematically below the outdoor cooling tower, will provide controlled cooling to simulate any cooling tower condition to support the four LTR test loops and the two system chambers. The chiller is scheduled for delivery and installation by the end of June, 1977.

2.4.3 HSF Qualification Test

Fabrication of the HSF qualification system began early February and was completed by late March. The limiting item in the build cycle was the 400 gallon TES tank which was received on 3/4. Interconnection to that tank and leak checking of the system was complete by mid March. After the system was insulated with 3 inches on the TES tank, 2 inches on the storage loop and distribution loop piping and 1.5 inches on the collector loop piping, system functional check-out was completed by 3/28.

System qualification testing began on 3/29 with the TES charge rate measurements and two of these tests had been completed by the end of the reporting period. These tests were at a 120°F and a 200°F primary loop input with the respective initial TES temperatures at 101°F and 140°F.

Figure 2.4.3-1 shows the HSF Qualification System.

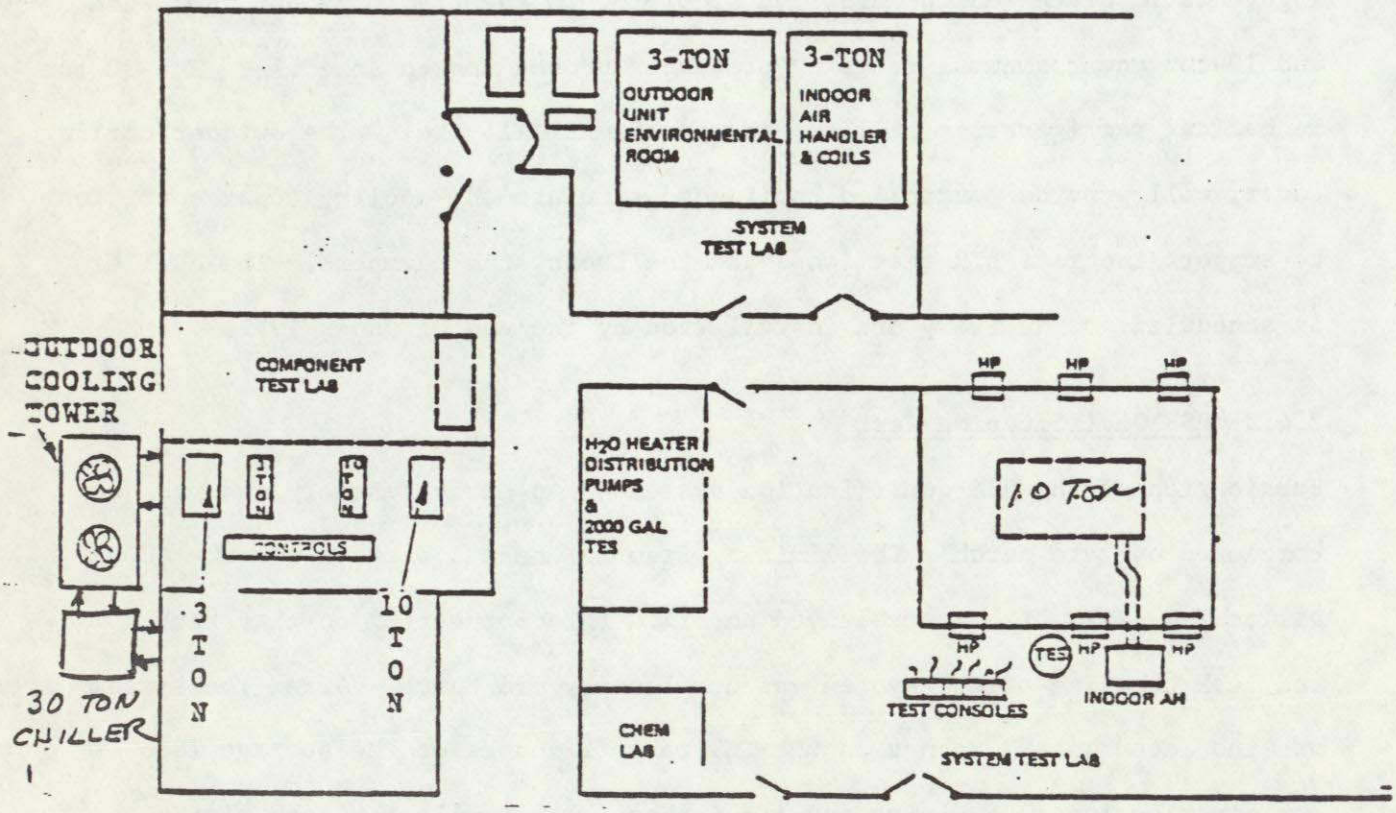

FIGURE 2.4-4 SYSTEM TEST FACILITY

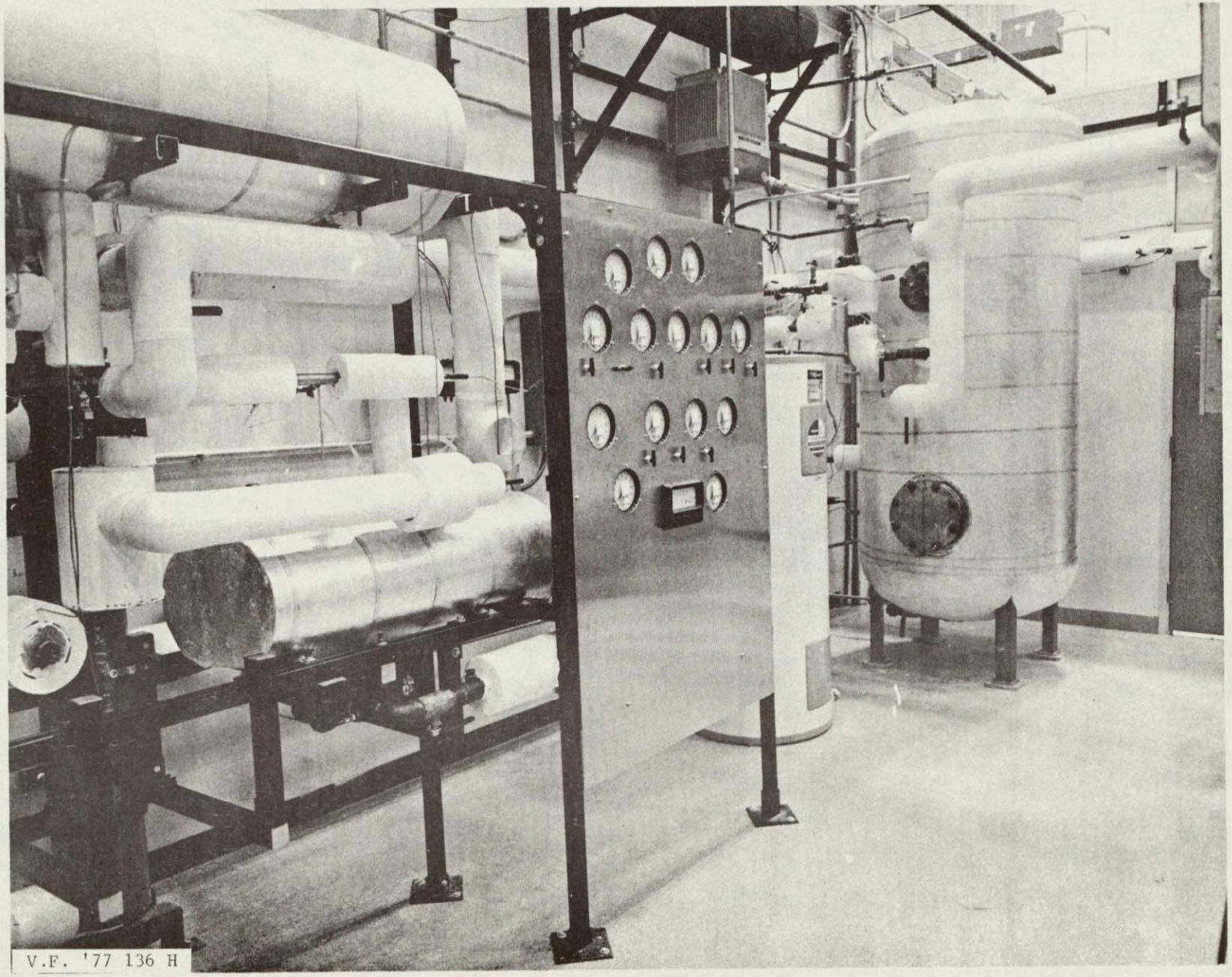

Figure 2.4.3.1. HSF Qualification System

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SECTION 3

TASK 1.3 - DELIVERABLE HARDWARE

Only limited activity occurred in this task since the Prototype Design Review is the event which initiates prototype hardware procurement. Procurement of long lead items for the solar collector for heating single family systems has been initiated. Activity is presently on hold pending resolution of problems encountered in installing shrouds on the qualification units.

SECTION 4

TASK 1.4 OPERATIONAL TEST

4.1 SITE IDENTIFICATION

Operational test activities began in this reporting period starting with the identification and inspection of sites selected by NASA MSFC. A number of sites have been investigated as defined in Table 4-1. The site having the compatibility with our systems as far as equipment is concerned with the house at Illinois State Univ., Normal, Ill. The site with the least compatibility was the staff quarters at the Veterans' Hospital in Albany, N.Y.

4.2 SITE DESIGN

4.2.1 ACTIVITY SUMMARY

Sites that were recommended to ERDA by NASA MSFC included the following:

HSF - Ft. Meade, MD
HSF - Normal, ILL.
HMF - Tullahoma, TN
HCOM - Muscle Shaols, AL
HCMF - Gt. Lakes, ILL

Conceptual design reports were completed and transmitted to NASA MSFC on the Ft. Meade, Muscle Shoals, and Tullahoma sites. Reports in progress include the Normal and Gt.Lakes sites.

The design of the Ft. Meade site has begun. GE has selected the firm of Collins & Kronstadt, - Leahy . Hogan . Collins to provide the installation design of the system. The architect for the Muscle Shoals site has been selected but design work was not started.

TABLE 4-1

SITES INSPECTED BY GE

Bldg. Type	General City	Site
HSF	Baltimore	7502 Young St. Ft. Meade, MD.
HCOM	Muscle Shoals	TVA office at Muscle Shoals, AL.
HMF	Nashville	Airman's quarters, AEDC, Tullahoma, TN.
HSF	Peoria	Chanute Air Force Base
HSF	Peoria	MHA, Champaign, ILL.
HSF	Peoria	ISU house, Normal, ILL.
HMF	Schenectady	MHA, Schenectady, N.Y.
HMF	Schenectady	VA Hospital Staff Housing Albany
HMF	Schenectady	Ely Park Housing, Binghamton, N.Y.
HCMF	Chicago	Ft. Sheridan, ILL.
HCMF	Chicago	Great Lakes Naval Training Center

The heating and DHW systems have been defined through a series of trade studies, as reported in Section 2.2.3, for the Ft. Meade, Tullahoma, and Muscle Shoals sites. Each site is discussed separately.

4.2.2 FT. MEADE, MD. HSF-1

The solar system proposed for incorporation into the Fort Meade single family residence will consist of 24 GE TC-100 vacuum tube collector panels mounted 38 degrees up from horizontal on the roof. This system size is obtained from a detailed examination of the cost effectiveness of the solar system which is defined using the levelized annual cost of the system divided by the annual energy produced. As shown in Figure 4-1, the system cost per BTU delivered reaches a minimum at 24 panels. The net effectiveness of the collector system defined as the energy supplied by the system divided by the number of panels is 0.17 MM BTU/FT^2. This value will be compared to the other system to determine the relative merit of each system. The TES tank will have a volume of 360 gallons which corresponds to the selected value of 1.0 gallon per square foot of collector.

4.2.3 TULLAHOMA, TN. HMF-1

The solar system proposed for incorporation into the Airman's Quarters at Tullahoma, Tennessee, will consist of 48 GE-TC-100 vacuum tube collector panels, a TES with a 710 gallon capacity and a primary loop heat exchanger (HX-1) having a surface area of 8.2 square feet. This system was sized to supply a minimum

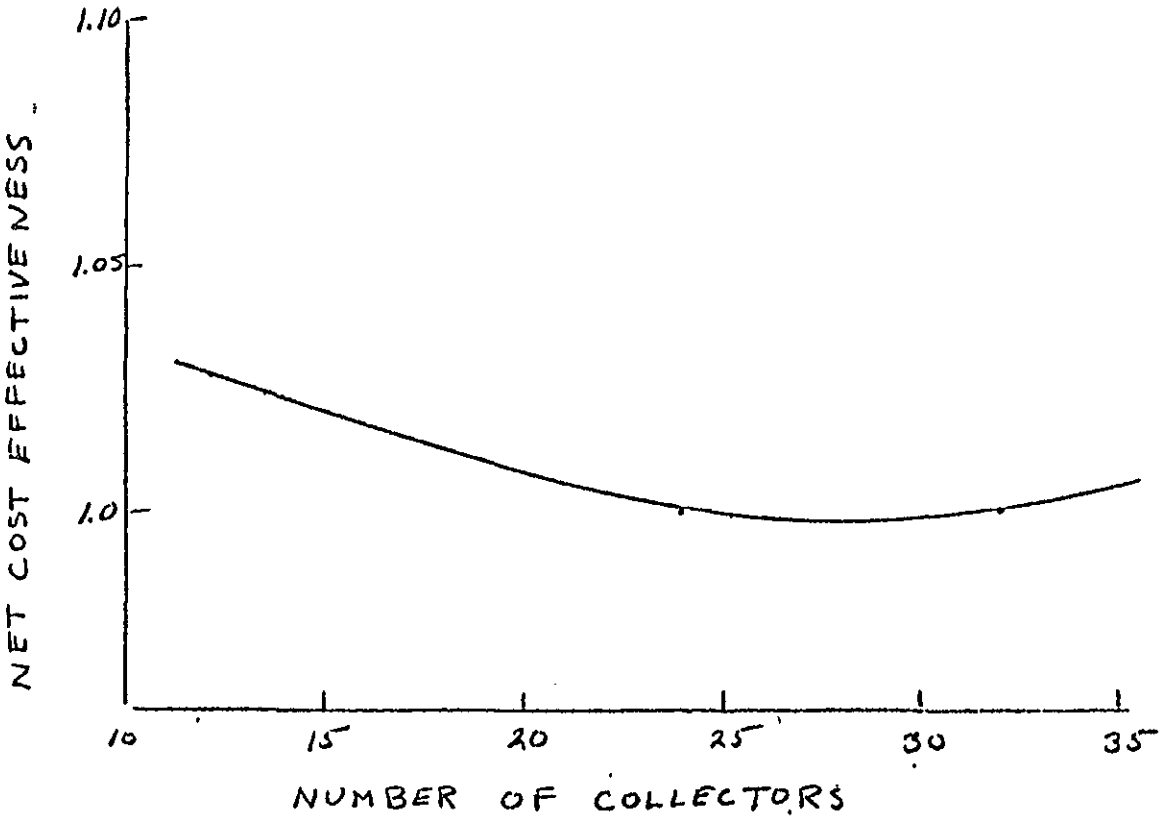

Figure 4-1. System Optimization Net Cost Effectiveness
Fort Meade Singe Family Residence

of 30 per cent of the space load. The net effectiveness of this system defined as the load supplied divided by the collector area is 0.149 MM BTU/FT^2. This value is close to but below the value of .17 MM BTU/FT^2 obtained for the Fort Meade application. The cloudy winter weather conditions characteristic of this region are largely responsible for reducing the net effectiveness of the system.

4.2.4 MUSCLE SHOALS, AL. HCOM-1

The selected solar system for the Muscle Shoals office building will consist of 72 collectors mounted at an angle 35 degrees from horizontal. The monthly energy which can be supplied by this system is shown in Figure 4-2. This system will provide approximately 50 per cent of the space and domestic hot water energy requirement of the building. The TES tank capacity will be 1060 gallons and the primary loop heat exchangers surface area will be 12.3 square feet.

The net effectiveness of the system, which is the amount of energy delivered divided by the collector area, is 0.086 MM BTU/FT^2. This value is approximately one-half the value of either the Ft. Meade or Tullahoma solar systems. The poor performance of this system is related to the cloudy weather which is characteristic of this region, the short heating season for this building, and the small domestic hot water requirement. There have been discussions of converting this site to a heating and cooling site to improve collector utilization and to better meet the site needs. The number of collectors was selected with some consider-

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Figure 4-2. System Optimization Building Engergy Requirements Muscle Shoals Office Building

ation of providing solar energy to a 10-ton solar cooling unit. Note that the selected number of collectors is not sufficient for solar cooling the entire building.

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